INFLUENCE OF THE SURROUNDING DIELECTRIC

on the

CONDUCTIVITY OF COPPER WIRES

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I N D E X.

TESTS OF THE EFFECT OF SOME DIELECTRICS ON THE ELECTRICAL RESISTANCE OF COPPER WIRES.

In 1892 Professor Fernando Sanford of Leland Stanford University, published a paper entitled "Some Observations upon the conductivity of a Copper Wire in Various Dielectrics"[1] describing some experiments that were undertaken with the object of finding if the dielectric surrounding a wire had any influence on its electric conductivity. He made measurements of a copper wire with about fifteen different dielectrics -- liquids and vapors -- and concluded that in general the conductivity was affected, in some cases increased and in others decreased, in one instance as much as 0.25 per cent.

In a later paper on "A Necessary Modification of Ohm's Law"[2] he referred to a similar observation made upon the conductivity of a silver wire, but the effect, though measurable, was somewhat less than in the case of the copper wire.

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1. Leland Stanford Jr. University Publications, Studies in Electricity No. 1.

2. Phil. Mag., January 1893 Vol. 35. Page 65.

Respecting the apparatus and method employed, he says: "The apparatus used consists of a cylindrical copper tube 120 cm. long and 2.5 cm. in internal diameter. The ends of the tube are closed air tight by copper plates, which are provided with stop-cocks for filling and emptying the tube. To the inside of one end plate is fastened a copper wire 1 mm in diameter, which passes length wise through the centre of the tube and out through an insulated opening in the other end plate, where it is soldered to a piece of lamp cord made of many small wires, by which it is connected with the Wheatstone's Bridge. Another similar piece of lamp cord is soldered to the end of the tube through which the wire passes, and is likewise connected with the bridge. Midway between the ends of the tube is another tube 5 cm. long and 1 cm. in diameter entering it from the side. This tube serves to admit the thermometer by which the temperature of the interior of the large tube is measured."

"The current used for making the measurements passes one way through the tube and returns through the wire. By this arrangement the entire field of force of the current to be measured is confined within the tube, and the whole of the dielectric concerned in its transmission can be changed at will."

"The measurements were made with a Hartmann & Braun combined resistance box and bridge, with bridge arms of 1 : 1000. The smallest resistance used was 0.1 ohm, which, with the above combination, represented a resistance in the wire and tube of .0001 ohm. The galvanometer used was the physiological galvanometer of Du Bois Raymond, manufactured by the Geneva Society Construction Company. It was provided with a concave mirror and a ground glass scale, and the usual method of observing the deflection of a spot of light was used. This deflection was plainly noticeable for a change of resistance corresponding to .0001 ohm in the wire and tube, and by reversing the current several times, it was possible to obtain a deflection for a change corresponding to one-fifth of the above. The measurements were accordingly estimated with a fair degree of accuracy to .00001 ohm. As the combined resistance of the wire and tube was about .0355 ohm. the average of any set of measurements was certainly not .03 of one per cent wrong".

"The strength of current through the wire and tube was always between the extremes of five and eight milli-amperes. The measurements were all made at the temperature of the room and as this changed very slowly, only a few measurements could be made in a day."

The temperature of the room changed sometimes as much as 10°C. in 24 hours but measurements were made at all hours of the day, and, on an average, as many were made with rising as with falling temperature. The thermometer was a standard, graduated to tenths. A temperature change of 0.1° C. made a resistance change of .000012 ohm, which gives a temperature coefficient of .0036

The following table shows some of the results he obtained for a copper wire 1 mm. in diameter, the conductivity in air being regarded as unity.

Dielectric	Conductivity.	Resistance Change	Equivalent Temp.change	Per cent change
Petroleum	1.0018	-0.00006 ohm	-0.43°	-0.18
Carbon bi-sulphide &	1.0009	-0.00003 "	-0.25	- .09
oil of turpentine Carbon bi-sulphide	1. - apparently but uncertain			
Wood Alcohol	.9998	+0.000007 "	+0.05	+ .02
Benzene	.9994	+0.00002 "	+0.14	+ .06
Wood Alcohol and Benzene	.9985	.00005 "	+0.36	+ .15
Absolute Alcohol	.9981	+ .000064 "	+0.43	+ .19
Wood Alcohol and Petroleum	.9978	+ .000075 "	+0.53	+ .22
Gasoline burning gas	.9982	+ .000058 "	+0.4	+ .17
Chloroform vapor	.99830	+ .00005 "	+0.36	+ .15
Sulphuric Ether Vapor	.99750	+ .000083 "	+0.6	+ .25
Alcohol Vapor	.99940	+ .000017 "		+ .05
C S_2 Vapor	1.			
Rarefied air	1. —			

Later, Professor Carhart published an account of an investigation in his laboratory[1], undertaken with a view of confirming or refuting Professor Sanford's conclusions. But this investigation gave only negative results.

Carhart's method was similar to Sanford's. His tube was 86.3 cm. long and his copper wire 0.7 mm. diameter. The resistance of his tube and wire at 21° was 0.0468 ohm. But he claimed for his galvanometer and bridge a sensitiveness 2.5 times greater than Sanford's. He measured the temperature of the wire in the same way as did Sanford, but his thermometer was graduated to half degrees instead of tenths. But instead of taking readings at the temperature of the room, his tube was heated by a water bath up to 30° and observations for resistance taken as the tube slowly cooled down to the room temperature. He tried only two dielectrics besides air - alcohol and kerosene - and finding no effect due to these, he concluded it was not worth while to try others.

Professor Sanford continued his investigations[2] using the original method throughout, but in his later work he employed a more sensitive galvanometer and a Nalder Bros. resistance box and bridge with arms of 1:10000, the comparison coils

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1. Phys. Review, Vol. I. Page 321, 1894.

2. Phys. Review, Vol. III. Page 161, 1895.

being divided to tenths of an ohm. With this apparatus he could measure his resistance with certainty to 1 in the fifth decimal place. This, he says, was sufficiently accurate for the work since the temperature could not be known with certainty to a greater degree of accuracy than 0.1 °.

Measurements were made with five different copper wires varying in diameter from 0.35 mm. to 1.66 mm., the object of using different sized wires being to find the effect of varying the surface. With the smaller wire the temperature change masked any effect that might be due to the dielectric. He found effects with a copper wire 1.27 mm. diameter, but on taking another piece from the same spool and hammering it flat, no change of resistance due to the dielectric was observed. He did not find any definite relation between the amount of surface exposed and the effect due to the dielectric. The amount of the effect seemed to depend on the particular wire used, since the percentage effect of no two wires was the same. Some of the observations, he says, lead him to believe that only a thin film of dielectric adhering to the wire, and possibly absorbed to some extent by it, is concerned in the resistance change. One of the observations was that when the surface of the wire was coated with a thin layer of paraffine oil no resistance change was found when the wire was replaced in the gaseous dielectric that previously produced a change.

In the paper here referred to (Phys. Review Dec. 1895) Professor Sanford speaks of "A memoir by Professor Grimaldi and Dr. Platania, of the University of Catania[1], giving the results of a long and very careful series of experiments upon the resistance of a copper wire in air and petroleum. The results show a degree of concordance quite remarkable, when the difficulties of the determination are taken into account. In every case the resistance of the wire in petroleum was found to be less than in air. This difference in resistance was, however, when reckoned as a percentage of the whole resistance of the wire, only about one-twelfth as great as in the case of the wire with which the phenomenon was first discovered by me; but the total variation in resistance

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1. Sulla Resistenza Elettrica dei Metalli nei diversi Dielettrici Memoria del Dott. Giovan Pietro Grimaldi, Professore di Fisica nella Regia Università di Catania, e Dott. Giovanni Platania, Assistente al Gabinetto di Fisica della stessa Università, Parte I. Ricerche sulla varizione di resistenza del rame nel petrolio. See also, Dal Bollettino mensile dell' Accademia Gioenia di Scienze Naturali in Catania Fascicolo XXXVIII. seduta del mese Dicembre 1894. Also Nuovo Cimento July, 1895.

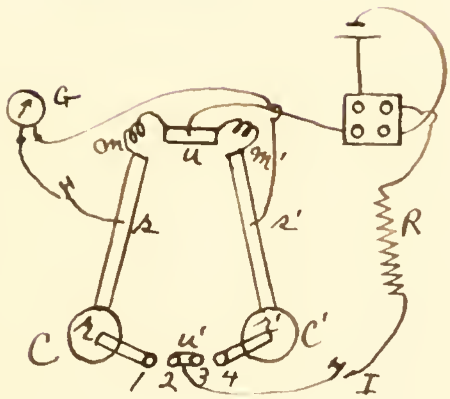
amounted, taking the mean of all the determinations, to 0.00002 ohm. while in the same dielectric with the wire originally used by me it amounted to 0.00006 ohm. The wire used by Signors Grimaldi and Platonia was 30.4 cm. long and 0.22 mm. in diameter. Its variation in resistance per unit length was accordingly greater than in the wire used by me, while the corresponding surface exposed was less than one-fourth as great".

Nearly a year after completing the work described in the following pages, I succeeded, through the kindness of Professor Carhart, in getting a copy of the paper by Drs. Grimaldi and Platonia here referred to. A few months later the paper was translated for me. Previous to this all I knew of their work was what I learned from reading Professor Sanford's remarks which, in the foregoing, I have quoted in full. Here he does not speak of their method; consequently, I knew nothing about it. I was, therefore, somewhat surprised, when the translation was given, to find that they had used a comparative method somewhat like the method I employed. They tried to keep the temperature constant just as I did. However, their method of determining the resistance change was inferior to that I employed, which was suggested to me by Professor Rowland, and which is the easiest and best method with which I am acquainted of comparing two nearly equal

resistances, one of which is known. I will now describe their method and state their results.

They made a series of observations with the apparatus connected first as shown in figure "a".

Figure "a"



C was a copper tube 40 cm. long and 5 cm. diameter. Passing lengthwise through its centre was a copper wire 304 mm. long and 0.22 mm. diameter, which was soldered at the bottom end to a rod projecting inward from the copper plug, and at the top to a rod which passed out through an insulating plug. C′ was like C, both wires of which were cut from the same spool, m and m′ were resistances each made by winding three metres of copper wire on a glass tube. 1, 2, 3, 4 were mercury cups. G was an aperiodic galvanometer of Siemens and Halske. Its resistance was 6 U.S. and its system almost astatic. In order to keep the temperature constant each of the four arms of the bridge was inclosed in a glass tube and then these four tubes were immersed in a 40 gallon water bath. In order to get the temperature of the interior of the tubes C and C′, a

standard Baudin thermometer, graduated to 1/20° C, was run down through the end of the tube until the bulb was at the centre. These thermometers were read through a telescope. By this means they thought they could estimate temperature to 0°.005 C.

The telescope and scale method of observing galvanometer deflections was employed. The scale divisions were 2 mm. apart and the distance between mirror and scale was 1.5 m. "The sensitiveness of the apparatus was such that a deflection of 2 mm. (i.e. one scale division) corresponded in the greater part of the measurements to a variation in the resistance of about 0.00010 ohm. By multiplying the measurements, when all the sources of error were eliminated, we were able to reach, as will be seen afterwards, a still greater exactness".

Through the bottom of tube C (or C′) passed a small tube by means of which C could be filled with petroleum, or emptied, without in any way disturbing C. The tube was dried after the petroleum was run out, by means of a Gay-Lussac pump. Measurements were begun by first getting the bridge nearly balanced in air. This was done by breaking and re-soldering the terminals of m and m′. This process was continued until the deflection was no more than 2 divisions. A change in the difference of these two resistances was estimated by noting the change in the galvanometer deflection.

In order to get absolute values the deflections were calibrated. This "was done by means of two auxiliary resistances formed of two pieces of copper wire cut from the same spool as before, 10 mm. and 6 mm. long, respectively, which were soldered to two larger copper rods. These resistances, I and II, were intercolated in turn between the mercury cups 1 - 2 and 3 - 4, and the corresponding galvanometer deflections observed. To carry out the reductions, the absolute values of I, II and the copper tubes were measured by means of an excellent decadico bridge of Carpentier".

Value of I = 0.007 ohm; of II = 0.004 ohm; of C = 0.141 ohm; of C′ = 0.144 ohm. C ≡ right tube; C′ ≡ left tube.

The deflections obtained by intercolation were:-

	Resistance I		Resistance II
With right tube	60.7 divisions		37.3 div.
" left "	63.7 "		40.5
Mean, K_1 =	62.2	K_2 =	38.9

Variation of resistance produced by one division, a_1 = 0.000112 ohm. a_2 = 0.000103 ohm. Mean a = 0.000108 ohm.

Having thus calibrated the galvanometer the deflection produced when air was in both tubes was carefully noted, this deflection ranging from one to two scale divisions. Under the same conditions, these small deflections differed among

themselves usually not more than 1/10 division. Testing for the effect of temperature they found as a mean of nine observations that a temperature difference of 0.1° C between the two tubes produced a deflection of 0.53 divisions, this mean being made up of values ranging from 0.36 d. to 0.?7 d.

Petroleum, dried over sodium and rectified, was then run into the right tube and observations made. Then the petroleum was run out, the tube dried, and observations again made. The observations first in air, then in petroleum, and lastly in air usually extended over several days in all. For illustration I here give the summary of one series of experiments which extended over nine days. This summary they called

TABLE IV. bis

Deflections

	Observed	Corrected
Petroleum	2.19 divisions	2.38 divisions
Air	2.45 "	2.54 "
Difference	- 0.26	- 0.16

K_1 = 69.0 divisions $\quad$ K_2 = 44.0 divisions

a_1 = 0.000101 ohm $\quad$ a_2 = 0.000091 ohm

a = 0.000096 ohm

	observed	corrected
Δ =	0.000025 ohm	0.000015
$\frac{\Delta}{R}$ =	0.00017	0.00010

where $K_1 \cdot K_2$, a. have the meaning given above.

Δ = change in resistance in ohms due to petroleum.

R = resistance of copper tube.

Corrected values mean those corrected for temperature.

With the apparatus connected as in figure "a" they made four series of measurements which are summarized in the following table:-

TABLE A.

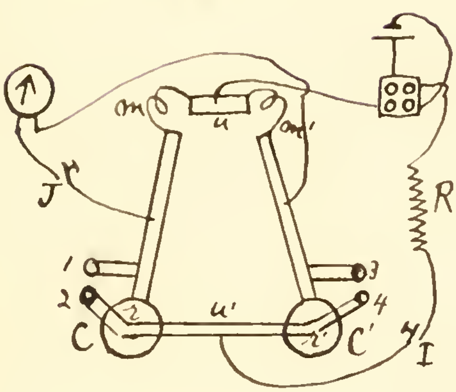
Table	Δ		$\frac{\Delta}{R}$	
	Observed	Corrected	Observed	Corrected
I^{bis}	0.000070	0.000054	0.00049	0.00038
II^{bis}	51	43	36	30
III^{bis}	70	55	4[illegible]	38
IV^{bis}	25	15	17	10

As seen, the result of Table I^{bis} and III^{bis} is nearly four times greater than that of IV^{bis}. Seeking a cause for these wide variations they found it in the mercury contacts which existed in the connection between the two tubes. They found the deflection depended on how the copper ⊓ 's connecting the mercury cups were placed; i.e. turning one of these connectors through an angle of 180 they obtained a different deflec-

tion. This they ascribed to contact E. M. F's. at the ends of these connectors. There were eight ways in which these two connectors might be placed, and they made observation of deflections with the connectors in each of these positions with the result stated.

The connections were then modified as shown in figure "b". By this change the mercury cups were removed from the direct circuit, and were put in shunt circuits. In order to calibrate the galvanometer deflections, a resistance ρ made of copper wire and of the value 3.57 ohms was connected in shunt first with one tube and then with the other. The change in deflection produced was about 56 divisions

Fig. "b"



In connection with this change it is remarkable that the idea did not occur to them to make the method of comparing the two tubes a zero one. This could easily have been done by making the resistance of C′ more nearly equal to that of C, and then securing a balance by shunting C′ with a standard resistance box. Then the method would have been exactly the one I employed, and would have been a great improvement on

the method they finally used.

With these changes made they began anew to investigate the influence of petroleum, trying three different specimens of this dielectric, all carefully dried and rectified. The order of measurements was a comparison of the two tubes with air in both, then with petroleum in one, and finally again with air in both. This series of experiments extended in different cases over a period of time varying from eight hours to four days. The results are summarized in the following table:-

T A B L E A.

Series	Δ	$\frac{\Delta}{R}$
V	0.000023 ohm	0.00017
V^a	20	14
VI	20	15
VII	14	10
VIII	25	18
IX	18	13
X	18	13
mean	0.000020	0.00014

difference ± 0.000005 ohm ~~± .00004~~ ± 0.0004

The results therefore give as mean a decrease of about 0.014%.

In making up the mean of the observations in the series of Table A,, they rejected the readings if the temperature difference between the two tubes was greater than 0.03° C Discussing their results they think the effect was not due to extraneous E. M. F's. for these had been eliminated by dispensing with the mercury contacts. Neither are they due to thermal effects, they think. for the observations were all consistent whether the temperature of the petroleum tube was above or below that of the air tube. And the effect was observed whether the petroleum was in one tube or the other, though as a matter of fact in all the above series of measurements, the petroleum was in the tube C, i.e. the right tube, as they have designated it. Lastly, the effect could not be due to the conductivity of the petroleum for a test showed that if the conductivity had been 50 000 times greater than it was, then no error would have resulted from this cause. They conclude, therefore, that the decrease in resistance must be due to the influence of the petroleum, and amounted to 0.014%. Sanford gave as his result a decrease of 0.18% while my results show that the effect, if any, was an increase not greater than 0.002%. My observations on this dielectric give remarkably uniform results, no single set of observations giving an effect greater than 0.002%.

As an illustration of the agreement among their observations I will here give entire a table comprising series VII of

their measurements. I chose this table because the temp-erature differences between the two tubes in this series were a minimum.

TABLE VII.

Petroleum B. Duration of experiment thirty hours.

Observation Number.	Temperature		Temp. Diff.	Deflection.	
	Right Tube	Left Tube		Observed	Corrected
		Air			
279 A	26°895	26°870	+0°025	1^d.63	1^d.75
280	26.855	26.880	-0.025	1 .93	1 .81
281	26.885	26.900	-0.015	1 .80	1 .73
282	26.805	26.910	+0.005	1 .72	1 .70
283	26.925	26.920	+0.005	1 .70	1 .72
284	26.925	2[illegible].930	-0.005	1 .70	1 .68
285	26.975	26.970	+0.005	1 .65	1 .67
286	26.995	27.000	-0.005	1 .63	1 .61
299 C	26.895	26.880	+0.015	1 .73	1 .82
300	26.975	26.950	+0.025	1 .80	1 .92
301	26.985	26.970	+0.015	1 .80	1 .87
302	26.855	26.850	+0.005	1 .87	1 .89
303	26.825	26.850	-0.025	2 .10	1 .93
304	26.825	26.850	-0.025	1 .90	1 .[illegible]8
305	26.825	26.840	-0.015	1 .86	1 .[illegible]
				mean	1 .78
		Petroleum			
291 B	27.075	27.070	+0.005	1 .83	1 .85
292	27.095	27.090	+0.005	1 .80	1 .[illegible]
293	27.085	27.090	-0.005	1 .90	1 .88
294	26.745	26.730	+0.015	1 .93	2 .00
295	26.755	26.750	+0.005	1 .94	1 .96
296	26.775	26.770	+0.005	2 .00	2 .02
				mean	1 .93

Table VII^{bis}

R_r = 0.159 ohm R_l = 0.144 ohm. ρ = 3.57 ohm.

	Corrected Deflection
Petroleum	1.93 divisions
Air	1.78
Difference	0.15

Placing ρ in Shunt

With right tube	58.7 divisions
" left "	57.4 "
mean K =	58.0
a =	0.000095 ohm
Δ =	0.000014 ohm
$\frac{\Delta}{R}$ =	0.00010

where R_r ≡ resistance of right tube

R_l ≡ resistance of left tube

a ≡ resistance in ohms required to produce a deflection of one division.

Now in Table VII, A means the series of measurements taken before the right tube was filled with petroleum; B was the series taken with the petroleum in the tube, and series C was made after the petroleum was run out.

In examining all the tables of the paper one finds two or three features which are remarkable. One is that deflections are recorded to a hundredth of a scale division, i.e.

to a fiftieth of a mm. The authors do not say how they succeeded in reading deflections through an ordinary telescope to such a degree of minuteness. In striking contrast to this is the fact that resistance values of R_2, R_1 and ρ are not given beyond the third decimal place, and the method of calibrating the galvanometer deflections was certainly not very exact.

Again in every table the difference in deflections between the series C and D is less than between series A and So that by varying the number of observations in series C and A, respectively, that go into the final value of the mean deflection in air the apparent effect due to petroleum will vary in some cases 100%. For instance, in ~~the~~ table VII the mean of series C is 1.87 divisions. This gives as a difference in deflection due to petroleum 0.06 divisions and the corresponding Δ = 0.000005 ohm.

I give the result of comparing the mean of C with D in the following table, which I will call Table A_2.

Table A_2.

Series	Δ
V	0.000013 ohm
VI	17
VII	05
VIII	25
IX	09
X	14

Mean 0.000014 Mean $\frac{\Delta}{R}$ =0.01

Hence according to these results the decrease due to petroleum was .01%, and not .015%, nearly, as they give. But it is a question how much weight should be given to quantitative results derived from deflections that differ by a fiftieth of a m.m. To me it seems that the experimental error in these readings is comparable to differences obtained

But that the petroleum did actually produce a slight decrease in the resistance seems probable in view of the fact that every observation made pointed in this direction. But whether this result would have been obtained had they polished the wire is a question. They say nothing about the surface of the wire, hence presumably they did not polish it

I first polished my wires and the galvanometer I used was about a hundred times more sensitive than theirs.

Moreover, they said they dried the tube after running out the petroleum by means of a Gay-Lussac pump. If they did nothing more than this to dry the tube, it seems more than probable that they never got the tube entirely free from petroleum after it was first filled. And if Sanford's observation was correct that the effect seemed to be the same whether the tube was filled or whether a thin coating only adhered to the wire, then they should have observed no change after the first introduction of the petroleum. But possibly they used some volatile solvent to free the tube of petroleum; Of this, however, they do not speak.

In trying to account for the supposed phenomenon Professor Sanford says, "The only explanation which I am able to offer [of the resistance change due to the dielectric] is based upon the assumption that the passage of a current through a metallic conductor is accomplished by means of disruptive discharges from molecule to molecule through the intervening ether."

His own results, however, prove to my mind, if they prove anything at all, that the effect of the dielectric is confined to the surface of the wire, and are just such effects as might be expected, so far as an increase of resistance is concerned; for the first wire used had an oxidized surface, and, in general, its resistance was increased when it was immersed in a dielectric. But when the wire had a clean bright surface, as the hammered wire must have had, no resistance change due to various dielectrics was observed.

But if the phenomena observed by Sanford really exist, independent of the accidental conditions of the surface of the wire, i.e. are not merely "surface effects", it seems to me important to establish the fact as it might throw some light on the nature of metallic conduction.

But it appeared to me that neither the method of Sanford nor that of Carhart was entirely satisfactory, for the reason that it was an absolute method and not a comparative

one. Furthermore, the method of measuring temperature was certainly not as refined as the suspected phenomenon demanded. Hence it occurred to me that if the length of wire immersed in the dielectric could be increased and its temperature more accurately measured, the comparative method being employed to determine both resistance and temperature differences, that the supposed phenomenon could, beyond question, be proved to exist, provided it was of the order of magnitude reported by Sanford. With the very helpful suggestions of Professor Rowland and Ames, I therefore devised a method which enabled me to prove to my mind that if the various dielectrics used changed the resistance of the wires employed, this change was in no case greater than 0.01 of 1 per cent, which is 25 times less than Sanford reported as due to some of the same dielectrics. And with some modifications that experience has suggested, I am satisfied that a greater degree of accuracy can still be obtained.

The accompanying figures 1, 2, 3, and the photograph, will indicate the method and, to some extent, the apparatus employed.

Two thin-walled copper tubes D and A (Figs. 1 and 2), each 100.7 cm. long and 3.2 cm. diameter, were placed side by side in a larger zinc tube J, which was surrounded by water and was 8.4 cm. diameter and terminated at the lower end in a funnel, the stem of which, 1.2 cm. diameter, passed through

the bottom N of the zinc water jacket. This jacket was 122 cm. high and 25.4 cm. diameter; hence tube J was surrounded by a column of water 8.5 cm. thick. The tubes D and A were each fitted with a platinum thermometer "t", a mercury thermometer T. and a helix of copper wire "c", the conductivity of which was to be studied. The platinum thermometer was made from about 185 cm. of #30 platinum wire, B. and S. gauge doubled on itself and secured in a thin copper tube 9 mm. diameter and about 39 cm. long. which was fastened so as to pass lengthwise through the centre of either tube A or D. Fig. 1 shows the arrangement at the top and Fig. 2 at the bottom. One end of the platinum wire was secured at "g" to a piece of copper wire the other end of which was soldered to the copper plug H at Q. The other end of the platinum wire was soldered at "h" to an insulated copper wire which passed out through a small hole in H and was then soldered at E to the copper terminal "e". The two portions of the platinum thermometer wire were insulated from each other and from the containing tube by thin discs of "fibre" "a" placed at suitable intervals throughout the length of the tube and through which the wires were passed. The upper plug H of the Pt. thermometer tube passed through a vulcanite cap K which closed the tube A. The lower end of the platinum wire, where it was doubled on itself, passed through a thin piece of fibre "f" 4 x 6 mm..

which was secured to the plug "p" by means of a wire "w". The plug "p" was insulated by fitting into a vulcanite piece "v" fastened to the centre of the copper cap "c", which was soldered liquid-tight to the tube A or D. Thus the platinum thermometer was perfectly insulated from the tube in which it was placed.

The helix of copper wire C was made from about 39 feet of #18 B. & S. gauge, and the helix was about 1.9 cm. diameter. One end was soldered at O to the lower copper cap and the top end to terminal rod "e". Before winding into a helix the wire was polished with fine French emery paper. To insure the helix making no electrical contact with the Pt. thermometer tube, four thin glass rods of the length of the tube were tied to it 90° apart. The copper rods "b" and "e" were then the terminals of the helix and the tube A, "b" being soldered to tube at G. But "e" was also one terminal of the Pt. thermometer, the other terminal of which was a copper rod, not shown in fig., of the same size as "e", soldered to the plug H. Connection was made with the bridge by heavy flexible cords each composed of 110 strands of #24 copper wire. These cords were attached to the terminals by the method indicated at L (Fig.1). L was a short piece of #1 copper rod, 7.3 mm. diameter, bored out at each end, the lower hole tightly fitting the terminal "e", and the upper of the

shape and size indicated. The cord terminal fit into the lower part of this hole and was then fastened securely by allowing the Griffith fusible metal, with which the hole was previously partly filled, to solidify. This metal fused at such a low temperature that the connections could be broken without difficulty. The terminal rod "a", made of #6 copper wire (4 mm. diameter) was made more secure than indicated by the figure by means of a thick piece of fibre, perforated with suitable holes and then slipped down over the ends of the rod "a" and plug H.

T_1 and T_2 indicate two mercury thermometers that were inserted into the tubes to about the distance shown and served as indicators of the approximate temperatures of the tubes. They were made by Green of New York and were graduated to tenths of a degree, the degree divisions being fully a cm. apart.

W is the section of a circular disc of paraffined wood which covered, as shown, the tube J nearly water-tight. The tops of tubes A and B were about 5 cm. below the under side of this cover. The water in the jacket was maintained to the level "l".

Into the lower caps of tubes A and B were soldered two small tubes "I" which served to admit the liquids. A piece of pressure tubing fastened to I, passed down through the

stem of the funnel and was connected to a piece of tubing outside, the upper end of which could be raised or lowered at will. The dielectric liquids and vapors were run in and out of this tube without the apparatus being in any way disturbed. The rubber tube was closed at U by a pinch-cock.

The tubes A and D were held in place and insulated from one another at the upper end by a perforated paraffined disc of wood that fit the tube J (This disc not shown in fig.) This disc was split through the middle, a tube passing through each half. This arrangement permitted either tube A or D to be removed without disturbing the other. At the bottom end, the tubes were supported by a circular wood disc "r" that fit the tube J. To this disc was tacked a thinner disc "o" of fibre, and across the diameter was fastened a piece of fibre "i", 3 mm. thick and 6 mm. high, which served to keep the caps of the tubes from touching. Tests at different times showed that the tubes A and D were satisfactorily insulated from each other and from the tube J.

As to the bridge connections little need be said, as Fig. 3 makes them plain. B was the copper or platinum resistance, as the case might be, of the air tube A, and [illegible] the copper (or platinum) resistance of the dielectric tube D. These two resistances were in each case nearly equal [illegible] being slightly greater, an electrical balance being secured on closing the

circuit by a shunt box, S.

R and E were made as nearly equal to each other as could be. They were wound non-inductively on the same spool, the wires all being wound together, so that subsequently there would be no difference in temperature, or the difference would be so small that no error could result from this cause. The arms, R and E, of the bridge, corresponding to the copper resistances. F and D. were wound with #24 copper wire and were but slightly greater in resistance than F and D.

The resistance of the platinum thermometer was about 7.4 ohms while R and E in this case were only about 4.6 ohms, and were wound with #25 German silver wire. The terminals of F and D were held firmly to the bottom of the mercury cups by elastic bands which were fastened one end to the bridge and the other to hooks in the terminal rods of the flexible cords. Each rod was held by two bands. The bottom of the mercury cups were all bored out with a grooved flat-end bit and were then amalgamated. This precaution was taken to secure as good a contact as possible. The commutator C was weighted and care taken to secure good contact with the bottom of all the cups. There was also a commutator in the battery circuit and both direct and reverse current used in nearly all the measurements. The battery was a portable storage cell and R was a resistance of 106 ohms to reduce

the battery current to 20 milli-amperes or less. Besides, when the copper resistances were being measured, there were about 10 milli-amperes going through F and D.

Since the platinum and copper resistances had a common terminal, to change from the measurement of one to the other, the terminals in cups "m" and "n" only had to be removed and the proper ones inserted. The spool of auxiliary resistances, R and E, was also changed. Of course the platinum and copper resistances D each had its own separate shunt box. These boxes had been recently calibrated by Willyoung. One was a 10,000 ohms box and the other a 1000 ohms box.

The galvanometer used was the one first made for Messrs. Mendenhall and Saunders[1]. It was fitted with a Wiess system, which was astaticised to a free period of about 7 sec. and increased to 14 sec. by a controlling magnet. The system was suspended by a quartz fibre. The system was made of two strongly magnetized #12 sewing needles glued to a strip of mica and were about 1.7 mm. apart. The mirror was made of thin glass and was 3 x 4 mm. in area. The deflections were read with a telescope and scale. The coils of the galvanometer were all connected in parallel, the resistance then being about 3.4 ohms. The sensibility with my system was somewhat less than that obtained by Messrs. Waidner and Mallory with a similar instrument[1], but it proved to be sufficiently high for the work. It was $C = 1.5 \times 10^{-9}$ C = current in amps. re-

1 Univ. Circulars, June, 1897.

quired to produce a deflection of 1 mm. at distance of 1 metre. But when the period was increased to 14 sec. the sensibility became correspondingly greater, the above being for complete period of about 10 sec.

To reduce to a minimum the disturbing effects of thermal currents in the galvanometer circuit, the key in this circuit was kept constantly closed and was opened only at the instants the battery circuit was being closed or opened. The opening and closing of these circuits was done as quickly as possible to avoid giving the galvanometer needle time to move much. The thermal currents were at times quite strong, deflecting the needle as much as 15 cm. Ordinarily, however, the deflection from this cause was 1 - 5 cm., the scale being about 110 cm. from the galvanometer mirror.

The photograph will show the means employed to prevent sudden changes of temperature in any part of the apparatus. The water jacket was wrapped with a thick layer of felt, the top of it was covered by two board covers, one 1.5 cm. thick and the other 2.5 cm. thick. The flexible cord junctions with the resistances were all protected by being enclosed in a box with plate glass front and back through which the thermometers T_1 and T_2 were read. This box had a movable top, and the arrangement at the back where the cords passed out was such that the plate glass window could be removed and the

box taken from the top of the tank without disturbing any of the connections. This box was wrapped about at the inside with cotton so as to protect the more the water and tubes from heat changes due to temperature variations of the room.

The bridge, shunt boxes, and keys were also enclosed in a box made of inch stuff, as the photograph shows. Note the battery and galvanometer keys could be closed by levers from the outside, a glass window being placed in front of each key so that the contacts could be observed. The galvanometer key was in the right lower corner of the box and the photograph shows the lever and its weight by means of which the key was kept closed. The battery key, which was attached to the bridge, was just behind the other window shown in the box. This key was closed by a push rod of wood, seen projecting from the top of the box. The bridge commutator was also reversed from the outside by means of a wood handle and the change of connections from copper to platinum resistances was also made from the outside. The photograph shows the thermometer that indicated the temperature of the box.

To protect the bridge from temperature changes that might arise from opening the box to change the shunt box plugs, a vertical partition was put in the box between the bridge and the shunt boxes. Furthermore, a thin horizontal wood cover, insulated by fibre from the boxes was pierced

with suitably placed holes large enough for the metal part of the plugs, protected the shunt boxes from the heat of the hand, even when the top cover was removed. The plugs could thus be operated while the shunt boxes were practically enclosed, and the more so, because the box cover was made of several narrow pieces only one of which was removed for changing the plugs, the one removed depending on the plugs to be changed. There was a distance of about 8 cm. from the top cover to the thin shunt box cover.

The flexible bridge cords were covered with insulating electric tape and then dipped in a paraffine bath, and were further insulated, when they passed through the box covers, by sheaths of gum tubing.

With the arrangement indicated above it was thought that a differential method was obtained which would give good results. The conductivity of a copper wire in the air tube was to be used as a standard with which the conductivity of an exactly similar wire in the dielectric tube was to be compared, the two wires being just alike in material and arrangement and of almost equal resistance. Being so arranged it was thought that their temperature would be the same, or would become the same on standing. But in order to measure the difference in temperature, if there should be any, the platinum thermometers were employed, these being so arranged that the platinum wire extended through the entire length of

the tube, and would thus indicate the average temperature of the tube, provided the two ends differed.

A weakness in Sanford's and Carhart's methods was that the temperature was measured at one point in the tube only, and then the assumption made that this was the temperature of every part of the tube.

I first thought of using a differential air thermometer to indicate any differences in temperature of the two tubes, and the tubes containing the platinum wires were designed to be the bulbs of these thermometers, the platinum thermometers to be used merely to calibrate this differential air thermometer. But after considerable time spent in adjustment and trial, I finally had to abandon the air thermometer and depend upon the platinum for subsequent measurements, for the reason that the differential air thermometer could not be made sensitive enough. Capillary tubes of different bores were tried as index tubes, and mercury, sulphuric acid, etc. tried as indices. But owing to the inertia and friction of the index and the comparatively small bulbs of the thermometer, the sensitiveness was not satisfactory.

Further, it was the original intention to test the conductivity of the wires at different temperatures, and the water jacket was provided with a coil of German silver wire passing from top to bottom of the jacket, which was designed

as an electric heating coil. But preliminary tests proved that it would be far better to keep the water jacket at as nearly a constant temperature as was obtainable. For the air tube and the dielectric tube would not heat at the same rate, and, as the effect to be measured proved to be certainly less than that caused by a small fraction of a degree difference in temperature, this effect, if any, could be more accurately measured if there were no temperature difference in the two wires. A test was made of the constancy of the temperature of the water from the city system, with which the Ryerson Physical Laboratory is connected, and this test gave even better than expected results. During one test of two hours duration the temperature did not vary hardly a readable amount on a thermometer graduated to tenths. Hence the water jacket was connected with the water mains, and the water kept running through it day and night without ceasing.

A room on the ground floor with a north exposure only was obtained in order that temperature variations might be reduced to a minimum.

These arrangements to reduce temperature variations to a minimum were quite satisfactory on the whole but during the last few days of work it was found that they were somewhat defective, for the weather quite suddenly became very warm, and, as a result, the room temperature was considerably

above the water temperature; and it was found that, under these conditions, the top part of the jacket was not sufficiently wrapped to prevent the temperature of the top part of the air and dielectric tubes from rising above that of the surrounding water, occasionally several tenths of a degree. For this reason I have not quite the same confidence in the measurements of the last three or four days that I have in the others

In order to have the dielectric when put into the tube of nearly the same temperature as the tube itself, the bottle containing the liquid was put in a running water bath, supplied with water from the same source as the jacket, and kept there for several hours before using.

With the method employed, in order to make the comparisons, it was necessary to determine the resistance temperature-coefficient of the platinum wires, and to find the approximate resistance of the copper and platinum wires in the air tube, which were to serve as standards, and then to compare the resistances at the same temperature in air of the wires in the dielectric tube with the corresponding wires in the air tube. Then difference being found under these conditions, the variation of this difference when the dielectric of one tube was changed could be measured.

Now, since like wires in the two tubes were of nearly the same resistance, those of the air tube being slightly

greater, it would make no difference how the temperature varied, provided the variation in the two thermometers was just the same. Furthermore, the resistances of the wires used as standards would not have to be known to the greatest degree of accuracy. However, they were measured with some care.

The temperature coefficient of the platinum wire was determined both before and after being made into the thermometer. At first, between 9 and 10 ohms of the wire were wound non-inductively on a spool that the Ryerson Physical Laboratory possessed for that purpose, and then immersed in an oil bath, provided with a suitable stirrer and a tenth degree thermometer. This oil bath was heated, or cooled, by being inserted in a larger water bath. The method of measuring the resistance was the same as that subsequently employed and is indicated by Fig. 3. A 10 ohm standard coil was shunted by a certified resistance box until its resistance equalled that of the platinum wire. This measurement gave as the resistance temperature-coefficient 0.00174. The wire was then unwound and made into the two thermometers, annealed, and its temperature-coefficient again determined. It was annealed by an electric current, being heated very slowly up to red heat by increasing current, and then slowly cooled by decreasing the current. This was repeated several times. The

thermometer tubes were then placed side by side in a bath of water which had the room temperature. The resistance of each was measured by the same method as before - shunting a standard 10 ohm coil. The water bath was then replaced by a bath of shaved ice, and, after the tubes had been buried in this for about six hours, several measurements of their resistance were made. As a result of these measurements the temperature-coefficient was found to be .00180, an increase over that before obtained. This increase must be due to the annealing. But, further, the conditions were such that this determination is certainly more reliable than the other. The coefficient, as determined for each tube separately, was found to be the same, the two differing not more than a fortieth of one per cent. Hence I regard .00180 as the temperature-coefficient, correct to at least one per cent. But an error of one per cent would have, plainly, an entirely negligible influence on subsequent results.

The value of the resistance of the copper and platinum standards of the air tube was determined by measurement with a Queen standard bridge, Anthony form, the ratio of the arms of which could be made 1 :10000, if desired, and the rheostat had ten 0.1 ohm coils, in addition, of course, to larger coils.

Now, using the Jenkin bridge and shunting the standard to secure a balance, the value of the resistance compared

with the standard, in terms of the standard, is

$$R = \sqrt{R_1 \times R_2}$$

where $R_1 = \dfrac{\text{Standard} \times \text{No. ohms in shunt box}}{\text{Standard} + \text{" " " " "}}$, with the

commutator in one position, and

$R_2 = \dfrac{\text{Standard} \times \text{No. ohms in shunt box}}{\text{Standard} + \text{" " " " "}}$, with the commutator reversed. But in the measurements

$$R_1 \times R_2 = \frac{R_1 + R_2}{2}$$ because R_1 and R_2 were

almost equal, differing about (.02%) at the same temperature.

The months of June and July were spent in finishing and adjusting the apparatus and in preliminary tests. The galvanometer system had to be made and adjusted and this required considerable time, for the making of quartz fibres and such a minute galvanometer system was new to me. And it was not until the beginning of August that final measurements were to be made.

If

P = resistance in ohms of the platinum thermometer of air tube

P_1 = resistance of the platinum thermometer of dielectric tube.

W_1 = the resistance of the copper air tube and helix

R_2 = the resistance of the copper conducting tube and helix.

R' = the resistance of the shunt when commutator is in one position

R'' = the resistance of the shunt when commutator is in the other position

R_1 and R_2 the values above assigned, then

$$W_2 = \sqrt{\frac{W_1 \times R'}{W_1 + R'} \times \frac{W_1 \times R''}{W_1 + R''}} = \frac{\frac{W_1 \times R'}{W_1 + R'} + \frac{W_1 \times R''}{W_1 + R''}}{2} = \frac{R_1 + R_2}{2}$$

$$P_2 = \sqrt{\frac{P_1 \times R'}{P_1 + R'} \cdot \frac{P_1 \times R''}{P_1 + R''}} = \frac{\frac{P_1 \times R'}{P_1 + R'} + \frac{P_1 \times R'}{P_1 + R''}}{2} = \frac{R_1 + R_2}{2}$$

Where, in this second case, R' and R'', R_1 and R_2 are, of course, not the same values as they are in the first case.

In order to keep contact e.m.f's. down to a minimum no acid or soldering fluids were used in the soldering of any of the joints, and, as far as possible, copper was the only metal used in the circuit, the joints, therefore, being the contact of two like metals. And where, as in the case of the platinum thermometer, two unlike metals were joined, the opposite ends of the platinum wire were brought near together, as Fig. 1 shows, so that their temperatures would be the same.

further details will be given in the following report of

RESULTS:-

The fixed arms of the Jenkin bridge, R and E, were compared. Those for use with the platinum thermometers differed by .0003 ohm, the greater being 4.6605 at 27° C.

Those for use with the copper helices differed by not more than 0.0001 ohm, or they agreed about as closely as could be measured with the Queen's Anthony bridge and the galvanometer used. (A galvanometer belonging to the Ryerson Physical Laboratory). The value of one arm was [illegible].30735 ohm at 27° C.

As a mean of several closely agreeing measurements at different hours with the Queen's Anthony bridge the platinum thermometer for air tube, or

P_1 = 7.3864 ohms at 22°.7 C.

The copper air tube and helix was

W_1 = 0.27570 ohm at 22°.7 C.

These latter measurements of P_1 and W_1 were made when the tubes were in place in the water jacket, etc. A series of measurements were now begun and continued through three days, Aug. 6th, 7th, and 9th, to find the difference between the two copper resistances and the two platinum resistances. The 8th being Sunday, the tubes had been standing side by side

in the water [illegible] within four [illegible], of the temperature of the air surrounding the tubes did not vary more than [illegible] during the last 60 hours, according to observations made at different hours from morning until night, it was thought that [illegible] certainly had become of the same temperature.

The order of measurement was to secure a balance with the copper resistances by varying the shunt resistance of the copper tube and helix used as standard, the commutator being in one position, and the current in one direction. Then, with commutator as before, reverse the current. Next the commutator was reversed and a balance secured with both direct and reverse current. The commutator was then turned back to its first position and the whole series of measurements repeated. Following this, the platinum thermometer terminals were attached to the bridge and the same series of measurements made. Next the copper tube terminals were put back and the measurements of the copper resistances again made.

Frequently these different measurements would give exactly the same results, especially those with direct and reverse current. Hence in the majority of cases measurements were made with direct current only, reverse currents being used at intervals to see if there was any difference.

But in some of the following measurements, differences are seen to exist between successive series, and between the different measurements of the same series. But I am satisfied these differences were mostly due to variable [illegible]

of the commutator and terminals. Results, to be correct to the millionth of an ohm, will permit of the use [illegible] of but few contacts, let these contacts be as good as they may.

The temperature, as indicated by mercury thermometers, was observed of the interior of the box containing the springs and shunts and also the temperature of the interior of the top of the two copper tubes. These temperatures were not used in the deductions of results, because the variation of the box temperature was so small generally that the influence on results was negligible, and the temperature differences of the two tubes was measured by the platinum thermometers.

These were the observations and their results of Aug. 8th and 9th.

$V_1 = 0.27570$ ohms

$P_1 = 7.5834$

A[illegible]

Hour	T°	T_1°	T_2°	Dielect	R'	R"	R
A.M.						Cu	
9:00	24°[illegible]	22°62	22°62	Air	52.10	[illegible]	
					52.18	50	
						Pt	
[illegible]:30	25°	22°62	22°[illegible]	"	4370	3940	7.37[illegible]
					4370	3940	
						Cu	
10	25°	22.70	22.70	"	52.57	50.17	
				Mean	52.21	50.06	0.27[illegible]08

Aug. 9.

Hour	T°	T_1°	T_2°	Dielect	R'	R"	R
[illegible]							
						Cu	
7-45	24°2	22°[illegible]	22.6	Air	52.20	50.0	
					52.0[illegible]	50.0	
8-15	24°3	22°65	22°65	"	51.80	50.00	
					52.00	50.0[illegible]	
				"		Pt	
9	24°[illegible]	22°75	22.75	"	4530	39[illegible]7	7.37[illegible]13
					4530	39[illegible]5	
						Cu	
9-2[illegible]	24°[illegible]	22.76	22°76	"	52.12	50.20	
					52.12	50.20	
				Mean	52.05	50.1	0.27[illegible]

On Aug. 8 - R_1 = 7.37592 / 0.274312 and R_2 = 7.37[illegible]58 / 0.27[illegible]50

On Aug. 9 - R_1 = 7.37564 / 0.274307 and R_2 = 7.374[illegible] / 0.274[illegible]05

T = temperature of ice [illegible]

T_1 = temperature of air bath ⎫ according to mercury thermometers.
T_2 = " " dielectric tube ⎭

R' = shunt resistance in ohms for commutator in one position.

R" = " " " " " " reversed.

R = The resistance of dielectric tube and coil, or the platinum thermometer, as the case may be, i.e. W_2 or P_2.

T_1 and T_2 were observed only to give some idea of the approximate temperatures of the tubes.

The shunt box used for the copper resistance was a 1000 ohm box standardized by Willyoung. Its smallest division was 1 ohm. The fractions of ohms given in the table were determined by interpolation from the galvanometer deflections caused by 1 ohm difference in the shunt. This one ohm difference caused a deflection of 22 scale divisions. But 1 ohm difference in the shunt of the copper resistance corresponded to a resistance difference of about 0.000025 ohm in dielectric tube and coil. Hence a galvanometer deflection of one scale division would be caused by a resistance variation of one-millionth of an ohm, i.e. a change of a millionth of an ohm in the dielectric wire could readily be detected. But of course the platinum wire, having a greater resistance, could not be measured so accurately. The galvanometer needle was somewhat unsteady at times so that it required about five

ohms change in the platinum wire would not be [illegible] to produce a [illegible]-ive deflection of the needle. But with a [illegible] resistance of 4550 ohms, a change of five ohms would correspond to about 0.00002 ohm. i.e. to about 0.0012° C.

A 10000 ohm box, standardized by Willyoung, was used to shunt the platinum resistance of the air tube.

At 11 o'clock Aug. 9th the dielectric tube was filled with kerosene, by running the liquid in through the bottom of the tube as previously described, none of the connections or apparatus being in the least disturbed.

~~As previously described, none of the connections or apparatus were in the least disturbed.~~ When first run in the kerosene lowered the temperature of ice tube 0.3° below ice tube, according to the mercury thermometer.

Dielectric: Kerosene.

P_1 = 7.3664 ohms P_2 = 7.37513 } ohms in air
W_1 = 0.27570 " W_2 = 0.274279 }

For Pt. α = .00180

" Cu coil α = .0037

where $\alpha \equiv$ temperature coefficient.

Date	Hour	T°	T_1°	R'	R"	R
	P.M.				Cu.	
Aug. 9	1-45	24.7	22.95	51.15	49.54	
					Pt.	
	2-50	2[illegible]	23.900	4130	3765	
				4120	3775	
	P.M.				Cu.	
Aug. 9	4-30	25.5	23.904	51.21	49.50	
					Pt.	
	4-10	25.3	23.904	4210	3855	
				4203	3855	
				4207	3855	.27[illegible]
					Cu.	
	5-10	25.4	23.04	51.21	49.60	
			Mean	51.21	49.55	0.274[illegible]1

$R_1 = \frac{7.57[illegible]}{0.27[illegible]}$ $R_2 = \frac{7.57[illegible]}{0.27[illegible]}$

Hence R_2 is 0.00022 ohm less than in air, corresponding to 0°.021 C.

And W_2 is 0.000015 " " " " " which becomes 0.000003 greater when corrected for 0°.021.

Date	Hour	T°	$T_1°$	$T_2°$	R'	R"	R
	A.M.						
					Pt		
Aug. 10	10-3[illegible]	24°4	22°50	22.50	425[illegible]	[illegible]	
					42[illegible]0	[illegible]	
					42[illegible]0	[illegible]	
					42[illegible]	[illegible]	7.57[illegible]
					Cu		
	11-15	24°4	22°50	22.50	[illegible]1.7	4[illegible]	
					[illegible]1.32	4[illegible]	
					[illegible]1.70	49.50	
					51.[illegible]	4[illegible].45	
					[illegible]1.50	49.4	0.[illegible]

Dielectric: Kerosene
For Pt. R = 0.00016 ohm less than in air, which ≡ 0.015 C

Corrected for temperature the Cu resistance R = 0.[illegible] ohm, which is the identical air value.

Observations on effect of [illegible] (Continued)

Date	Hour	T	T_1	T_2	P'	P"	[illegible]
	P.M.						
					Cu		
Aug.10	5-10	24.4	22.0	22.0	51.30	49.78	
					51.05	49.5[illegible]	
					51.00	49.60	
					51.8	49.6	0.[illegible]
					Pt.		
	5-45	24.4	22.05	22.05	4260	3850	
					4250	3830	
					4260	3885	
					42[illegible]0	3866	[illegible]1500

Hence R_1 = 0.27311 and R_2 = 0.27439
.274300 0.274255

P_2 is 0.00013 less than air value which = 0°.010C, hence correcting V_2 the result is 0.274275, the air value.

Date	Hour	T	T_1	T_2	P'	P"	
	A.M.				Cu		
Aug.11	9	23.6	22.5	22.5	51.15	50.33	
					51.20	50.24	
					52.00	50.00	
					51.70	50.10	
					51.9[illegible]	50.10	
				(1)	52.1	50.15	
					Pt.		
	9-20	23.7	22.38	22.38	43[illegible]	39[illegible]	
					43[illegible]0	3940	
					43[illegible]	3935	
					4320	3930	
					4315	3935	
				(2)	[illegible]	[illegible]	

Date	Hour	T	t_1	t_2	R'	R"
Aug. 11	A.M.				Pt.	
	10-10	23°[illegible]	22°4	[illegible]	[illegible]	[illegible]
					[illegible]	39[illegible]
				(1)	[illegible]	[illegible]
					Cu.	
	10-20	23°[illegible]	22°4	22.4	51.[illegible]	[illegible]
					51.[illegible]	50.[illegible]
					51.90	50.5
					51.70	50.2
					51.[illegible]	50.3
				(2)	51.84	50.[illegible]

Dielectric: Kerosene.

					No.	R'	R"
	A.M.					Cu.	
Aug. 11	11-00	23°8	22°4	22°4		52.4	50.85
						52.4	50.75
					(3)	52.4	50.8
						Pt.	
	11-05					4370	3975
						4360	3970
						4360	3965
					(3)	4363	39[illegible]
						Cu	
	11-18					52.5	50.45
						51.9	49.65
						52.00	50.1
						52.0	49.[illegible]
						52.0	50.0
					(4)	52.10	50.00

	P.M.					Cu.	
Aug. 11	3-35	23°3	22°4	22°4		52.00	49.65
						52.25	50.2
						52.5	50.55
						52.0	50.25
						52.5	49.9
					(5)	52.3[illegible]	50.11

Observations on effect of [illegible] (continued).

Dielectric: [illegible]

Date	Hour	T	T_1	T_2	Cu.	R'	R''
	P.M.					~~[illegible]~~	~~[illegible]~~
Aug. 1[illegible]	5-3[illegible]	25°.[illegible]	25°4	25°4		45[illegible]5	3[illegible]50
						4510	394[illegible]
						4500	393[illegible]
						4500	392[illegible]
						4500	3920
							3920
					(e)	4507	3931
						Cu.	
	4-15	25°.9				51.4	49.6[illegible]
						51.5	49.50
						51.6	49.[illegible]
						52.0	49.4
						51.75	49.75
					(c)	51.65	49.6[illegible]

Mean of (1, 2, 3, 4, 5, 6,) gives R' = [illegible]

and R'' = 50.2

From which is obtained W_2 = 0.[illegible] ohm.
= 0.0000015 greater than air.

Mean of (a, b, c, d, e) gives R' = 450[illegible]

and R'' = 39[illegible] From which is

obtained P_2 = [illegible].57[illegible]20 ohms.

Now these values are almost identical with those obtained with air in the dielectric tube, the copper coil 0.0000015 greater and the platinum 0.0000[illegible] ohm greater, which corresponds to 0.005° C.

∴ R_2 = 0.27455, an increase of 0.002 per cent. Correcting for temperature, according to the indications of the platinum thermometer, the results obtained on Aug. 9th, and 10th, it is seen that in every case the copper has identically the same resistance in the kerosene as in air, the greatest difference being only 0.000005 ohm greater. Sanford reported a decrease of resistance in kerosene of 18% which would correspond in my tube and wire to a decrease of 0.000[illegible] ohm. Now, as previously stated, the sensibility of the galvanometer in the preceding measurements of copper resistance was such that a change of one-millionth of an ohm could be detected. Hence, it seems that if there had been a change of even 0.00001 ohm, or one-fiftieth of Sanford's percentage change, that I certainly could have detected it.

Of course there are variations in the shunt resistance in the above measurements, but I attribute these to variations in commutator contact, so far as concerns the same series of measurements; and perhaps the difference between successive series might be due partly to variations in the contacts of the terminals with the bridge, as well as to temperature differences. For, in general, if the copper resistances required a less value in shunt for a balance, the platinum resistances also required less. However, the extreme variation of the copper resistance on either the 9th, 10th, or 11th was no greater than 0.0000[illegible] ohm, which is

less than 0.006ω. I desire to call special attention to this result. The introduction of the kerosene lowered the temperature of the dielectric tube about 0°.5 below that of the air tube. It is hardly probable, therefore, that the temperature of the dielectric tube subsequently became higher than that of the air tube; and according to Pt thermometer indications, the temperature of the former tube was always slightly lower than that of the latter. But notwithstanding this the resistance of the dielectric tube, according to measurements made even three hours after the introduction of the kerosene, was smaller than its air value by less than 0.006ω, and this difference disappeared when temperature corrections were applied. Thus temperature and the reported effect of kerosene both, in this case, combined to make the difference great. It is remarkable, therefore, that this difference should be no greater than 0.006ω, since kerosene alone produced, for others, effects varying from 0.015ω to 0.18ω. The only conclusion is that kerosene here produced no effect.

After the above measurements, the kerosene was run out of the tube, and an accident, occurring to the rubber tube through which the liquid was run out, necessitated the removal of the dielectric tube from the water jacket and a breaking of the soldered joints with the flexible cords. Advantage was taken of this opportunity to remove the [illegible]

[illegible] in the dielectric tube. Much time has been spent in devising and making a stirrer that would be a non-conductor of heat from the outside and of electricity on the inside, and also one that would not touch the copper helix and raise its temperature by friction. Finally one was made that it was thought would answer these requirements. It was made of non-conducting material and seemed to move with perfect freedom in the tube. But various trials, while the tube contained kerosene, showed that in every case the temperature of the wires was raised by stirring even a part of a minute, as was proved by a decided increase in the resistance of both the copper and platinum wires. And since a stationary temperature was to be used in the subsequent measurements, a stirrer was thought to be unnecessary. But removing the stirrer necessitated a removal of the copper helix from the tube and, therefore, a resoldering of all connections. New measurements of the copper and platinum resistances in the air tube were then also made, as some modifications were also made in this tube.

The dielectric tube was freed from kerosene by running gasoline in after the kerosene was run out, and pumping the tube free of gasoline vapor, a bicycle pump with reversed valve being used to draw air through and an ordinary bellows to blow air through in the opposite direction.

When the tubes were adjusted, they were replaced in the water jacket, and after standing until the temperature [illegible] the same, measurements with the standard Queen's [illegible] bridge were made of the resistances, and temperature corrections applied to both the bridge and the wires. The temperature coefficient of the copper wire and tube as previously measured was $\alpha = 0.0037$, which I think is correct to at least one part in fifty. It was thought unnecessary to consume time in making this determination with the greatest refinement.

From the measurements made, the air tube and its copper wire had a resistance

$$W_1 = 0.2780[illegible] \text{ ohm at } 21°.[illegible] \text{ C}$$

The dielectric tube and wire had a resistance which was less by about 0.00155 ohm, i.e.

$$W_1 - W_2 = 0.00155 \text{ ohm.}$$

The platinum thermometer of air tube had a resistance,

$P_1 = 7.4000$ ohms at 22°. This was greater than P_2 by about 0.0164 ohms according to these bridge measurements. These differences, however, were much more accurately measured subsequently by the shunt method.

The insulation resistance between the two tubes was tested and found to be satisfactory (44,700,000 ohms), [illegible]-

[illegible] work [illegible] now with the [illegible] a series of measurements [illegible] with air in the dielectric [illegible] the following results :

T = temp. of bridge [illegible] boxes

T_1 = " " air tube per mercury thermometer

T_2 = " " dielectric tube per [illegible]

R' = Shunt resistance of copper wire and air tube with commutator direct

R'' = Shunt resistance of copper wire and air tube with commutator reversed.

W_1 = resistance of air tube and its [illegible]

P_1 = resistance of Pt. thermometer of air tube.

$$R_1 = \frac{R' \times W_1}{R' + W_1} \; ; \; R_2 = \frac{R'' \times W_1}{R'' + W_1} \qquad R = \sqrt{R_1 \times R_2} = \frac{R_1 + R_2}{2}$$

R', R'', R_1 and R_2 also have corresponding [illegible] with the Pt resistance.

For copper, temperature coefficient $\alpha = .0037$

For Platinum, " " $\alpha = .001$[illegible]

W_1 = 0.2[illegible]00 ohm at [illegible]

P_1 = 7.[illegible]000 ohm at [illegible]

Dielectric: Air.

Date	Hour	T	T_1	T_2		R'	R''	P
	A.M.					Pt.		
Aug.16	11-50	2393	21.[illegible]5	21.[illegible]5		3720	3410	
						3720	3410	
					(a)	3710	3400	
						3710	3400	
	P.M.					Cu.		
	12-15	"	"	"		52.25	50.0	
					(1)	52.3	50.0	
						52.2	5[illegible]	
						Pt.		
	12-35	"	"	"		3730	3410	
						3720	3420	
						3710	3400	
					(b)	3705	[illegible]	
							3400	
	2-15	2393	21.[illegible]0	21.[illegible]0		3710	3400	
					(c)	3720	3400	
						3710	3400	
					Mean	3715	3404	.[illegible]
	2-[illegible]	"	"	"		52.15	50.00	
						52.0		
					(2)	52.0	50.00	
						52.0		
					Mean	52.21	50.00	0.27[illegible]

In the above P was deduced from the values

R_1 = 7.3653[illegible]
0.276567

R_2 = 7.3[illegible]
0.276522

The observations of Jan. 16th were taken on the third day after connections were made with the Jenkin bridge. Observations were also taken on the 14th and 15th, and while they agree pretty well with those of the 16th, still the temperature conditions were such that I thought it best not to include the observations in the general average. And the constancy of the results on the 16th seem to indicate that equilibrium had been attained.

At three o'clock on the 16th absolute (?) alcohol was run into the dielectric tube, the temperature of which then fell 0.5° below the air tube, according to the mercury thermometers. The contact (?) e.m.f. due to the alcohol was so great that no readings could be taken with the platinum thermometer, for the galvanometer needle would be violently deflected on closing the galvanometer circuit. A reference to Fig. 1 will show that the platinum thermometer was not insulated from either the tube in which the platinum wire was stretched nor the dielectric tube. This deffect was subsequently remedied, but suffice now to say that the presence of alcohol in the tube made it impossible to use the platinum thermometer. And with the copper resistance, there was a "throw" of 2 to 3 cm. of the galvanometer needle on closing the battery circuit, the "throw" being exactly the same as would be caused by self-induction in the circuit.

These disturbances make it impossible to make any det-

isfactory resistance measurements that [illegible]. But R' was about 45 ohms and R" 41 ohms for copper. Next morning the temperature of the two tubes had become the same, according to the mercury thermometers, and the following measurements were made.

Observations on the Effect of Absolute (?) Alcohol.

$P_1 = 7.4000$ $\qquad$ $P_2 = 7.38407$
$V_1 = 0.27806$ $\qquad$ $V_2 = 0.276554$ } in air

Date	Hour	T	T_1	T_2	No.	R'	R"	R
	A.M.						Cu.	
Aug. 17	8-30	22°3	21.3	21.3		52.2	50	
						52.1	49.9	
						52.1	49.8	
						52.0	49.8	
						52.1	49.9	0.2765[illegible]

$R_1 = 0.276584$ and $R_2 = 0.276519$

From this V_2 is 0.000002 less than its air value.

Hence if we assume the temperature of the two tubes to be the same, as indicated by the Hg. thermometers, it can be said that the alcohol caused no change.

The alcohol was now run out, the tube closed and the following measurements in its vapor made, the "throw" of the galvanometer needle having disappeared.

Observations on [illegible] (a) Alcohol (~~[illegible]~~ Vapor)

Date	Hour	T	T_1	T_2	No.	R'	R"	[illegible]
	A.M.					Cu.		
Aug. 17	11-15	22°6	21°45	21°35		52.0	49.[illegible]	
					1	52.	49.[illegible]	
						52.	49.[illegible]	
	P.M.					Pt.		
	12-10	22.8	21°[illegible]	21°4		3610	3520	
					a	3615	3520	
						3615	3520	
						Cu.		
	12-20	"	"	"		51.8	49.[illegible]	
					2	51.8	49.[illegible]	
						Pt		
	12-30	"	"	"		3610	3520	
					[illegible]	3620	3520	
	1-[illegible]	"	"	"		3640	3550	
					c	3650	3540	
					Mean	3623	35[illegible]	[illegible].3[illegible]25
						Cu.		
	2-0[illegible]	"	"	"		52.0	[illegible].0	
					3	52.0	49.[illegible]	
					Mean	52.0	49.[illegible]	0.[illegible]

P_2 is 0.00042 ohm less than its air value = 0°.03[illegible] C

W_2 = 0.276583 corrected for temperature, [illegible]

0.0000[illegible] ohm which is 0.01[illegible].

Hence there seemed to be no effect due to the alcohol itself, but an increase of resistance of 0.02% due to the vapor, when the temperature corrections were made. Then a subsequent test showed that the alcohol was an electrolyte to a slight extent, so that this increase of resistance in its vapor was very probably due to previous electrolytic or chemical action while in the liquid. That there was a slight increase from this cause is shown by the fact that a subsequent test in air showed a slight increase over the former air value of 0.000030 ohm, i.e. of 0.01%. Taking this into account, i.e. comparing the vapor results with those of air as obtained afterwards, the increase of resistance due to the vapor was nil. Sanford, however, found an increase of 0.03%.

The slight conductivity of the alcohol would explain why the apparent resistance of the wire was not increased while the alcohol was in the tube even though its real resistance might have increased in consequence of chemical action. But, as said above, I could not measure the temperature of the alcohol, except by means of the mercury thermometer, hence cannot say whether or not the wire in the alcohol had the same temperature as the other wire. It is probable, however, that the temperature of the former wire was slightly below that of the latter.

The conductivity of alcohol and of the [illegible] was tested in a cell and with an e.m.f., [illegible]

view of testing whether the same conditions as the liquid was used as dielectric. The cell consisted of a glass tube 2.1 cm. diameter closed at one end with an accurately fitting copper plug which served as one electrode. The other electrode was a movable and adjustable copper plug inserted at the other end of the tube. The liquid was poured in and connections made with the standard Queen's Anthony bridge and the resistance measured in the ordinary way. The cell circuit contained commutator, and reversals were frequently made in the course of the measurements. The specific resistance of a cu. cm. of alcohol was found to be only about 30,000 ohms. The resistance of the kerosene was infinite.

The alcohol vapor was now drawn and blown out and then as the temperature of the two tubes approached equality observations began to be taken as follows:

Observations after [illegible] paper pumped out:-

Dielectric: Air. P_1 = 7.4060 P_2 = 7.3[illegible]7 Values
W_1 = 0.27606 W_2 = 0.[illegible]
previously obtained for air.

Date	Hour	T	T_1	T_2	No.	R'	R''	[illegible]
	P.M.					Cu.		
Aug.17	4-30	23	21°55	21°5		52.6	50.2	
						52.7	50.4	
					1	52 5	50 6	
							50.4	
	6-30	22.5	21°35	21.3		52.6	50.4	
					2	52.8	50.7	
						52.7	50.6	
						52.7	50.6	
						Pt.		
	7-20	22°5	21°35	21°35		3745	3415	
						3740	3400	
						3715	3410	
					mean	3733	3405	7.3[illegible]
						Cu.		
	7-45	"	"	"		52.9	51.0	
					3	52.8	50.7	
						53.1	51.0	
							51.0	
					mean	52.8	50.75	0.2765[illegible]

This gives W_2 an increase of 0.007, over previous air [illegible]

Observations after Alcohol Vapor pumped out.- (Con.)

Date	Hour	T	T_1	T_2	R'	"
	P.M.				Cu.	
Aug.18	7-55	22°	21°0	21.0	53.0	51.[illegible]
					52.85	50.[illegible]
					52.8	50.7
					52.8	50.4
					52.85	50.[illegible]
					52.9	50.5
						50.7
					52.85	50.78
					Pt	
	8-15	"	"	"	3740	3420
					3720	3410
					3730	3415

Dielectric: Air.

This gives practically the same values for P_2 and W_2 as did the readings of Aug. 17.

In a search for the cause of variation of R' and R" in the same series, the shunt wires leading to the shunt [illegible] were all resoldered and cleaned, the commutator cleaned and fresh mercury added, etc. Then the following readings were taken.

Further Observations on the Resistance of the Dielectric Tube after the Alcohol Vapor [illegible]:-

Dielectric: Air. P_1 = 7.4000
W_1 0.27806

P_2 = 7.38467 air values obtained Aug.16 before alcohol [illegible]
W_2 = 0.270554

Date	Hour	T	T_1	T_2	No.	R'	R''	P
	A.M.					Pt.		
Aug.18	11-55	23°3	21°3	21°3		3630	3540	
						3640	3540	
					a	3650	3540	
						3645	3540	
	P.M.					Cu.		
	12-10	"	"	"		53.4	51.	
					1	53.4	50.8	
						53.3	50.8	
						53.3	50.8	
						Pt.		
	12-35	"	"	"		3630	3530	
					b	3620	3530	
						3640	3540	
	2-00	23°0	21°25	21°25		3620	3520	
					c	3620	3520	
						3625	3520	
						3632	3532	7.384[illegible]
						Cu.		
	2-10	"	"	"		53.5	51.15	
						53.4	51.2	
					2	53.5	51.2	
						53.3	51.0	
						53.5	51.0	
						53.5	51.2	
						53.41	51.02	0.27[illegible]

This value of W_2 is almost identical with that obtained [illegible] alcohol vapor. Hence there is no doubt of [illegible] electrolytic action due to the alcohol, and it seems the vapor [illegible] effect.

But to test this matter again absolute alcohol was [illegible] 2-40 P.M. [illegible] in the dielectric tube. But, as before, its effect was such that no measurements could be made with the Pt. thermometer.

Part of Observations on the [illegible] of Absolute Alcohol and its Vapor:-

Dielectric: Absolute Alcohol. $R_1 = 7.4000$
$W_1 = 0.[illegible]$

$R_2 = 7.38429$ Values in air obtained Aug. 18
$W_2 = 0.270536$

Date	Hour	T	T_1	T_2	R'	R''	[illegible]
	P.M.				Cu.		
Aug.18	2-50	23°	21.4	21.26	50.5		
					50.7		
					50.8		
					50.[illegible]		
					50.9		
	3-15				51.5		
	4-45				[illegible].4		
	7-10	22.8	[illegible]	21.18	52.[illegible]	50.[illegible]	
					52.[illegible]	50.5	
					52.[illegible]	50.5	
						50.4	
					52.[illegible]	50.55	
	A.M.				Cu.		
Aug.19	8-20	22°	20.04	20.3[illegible]	53.0	50.9	
					52.[illegible]	50.8	
					52.[illegible]	50.8	
					52.[illegible]5	50.85	0.[illegible]

This value of W_2 is 0.000010 ohm less than in air [illegible] of dielectric tube also lower in temperature according to the thermometer.

Further Observations on the Effect of Absolute Alcohol and its Vapor (Con.). Dielectric: Alcohol Vapor.

Date	Hour	T	T_1	T_2	P'	P''	P
	A.M.				Pt.		
Aug.1[illegible]	9-00	22°[illegible]	?	20°9[illegible]	3620	3290	
					3615 3625	3300	
					3605	3310	
					3615	3310	
					Cu.		
	9-45	22°3		20°9[illegible]	53.4	51.1	
					54.1	51.[illegible]	
					54.1	51.[illegible]	
					54.1		
					Pt.		
	10-00	22°3		21.00	3620	3310	
					3620		
	P.M.						
	12-35	22		20°95	3620	3310	
					3620	3310	
					Mean 3620	3310	7.39[illegible]
					Cu.		
	12-45	"		"	54.1	51.7	
					54.0	51.[illegible]	
					54.0	51.7	
					54.0	51.[illegible]	
					Mean 54.0	51.[illegible]	0.2[illegible]

This value of P_2 is 0.00010 less than air value = 0°.00[illegible] C.

V_2 corrected is 0.27661[illegible] ohm, which is 0.009[illegible] greater than [illegible] air

The Alcohol Vapor was now (at 1-00 P.M.) pumped out and the following observations taken:-

Dialectric- Air

Date	Hour	T	T_1	T_2 To		R'	R"	R
	P.M.					Cu.		
Aug.19	3-40	21°8	20.85	20°85		54.	51.7	
						54.1	51.[illegible]	
					1	54.2	51.8	
						54.1		
						Pt		
	3-55	"	"	"		3620	3310	
					a	3620	3310	
						Cu.		
	7-15	21°8	20°7	20°7		54.1	51.[illegible]	
					2	54.3	51.[illegible]	
						54.0	51.[illegible]	
						54.	51.[illegible]	
	A.M.					Pt.		
Aug.20	7-45	20°8	20°37	20°37		3620	3310	
					b	3618	3307	
						3620	3310	
					Mean	3620	3310	7.3[illegible]
						Cu.		
	8-05	"	"	"		54.[illegible]	51.[illegible]	
					3	54.[illegible]	51.[illegible]	
						54.	51.[illegible]	
					Mean	54.06	51.35	0 [illegible]

These values of R_2 and [illegible]$_2$ are identically the same as those obtained in alcohol vapor. Hence this second series of measurements give for alcohol and its vapor the same results as did the first test with these dielectrics, i.e. the resistance in the liquid is the smallest trifle less than in air while in the vapor there is an increase in resistance of from 0.003 - 0.01% as compared with previously obtained air values, but no effect as compared with the air values subsequently obtained. I think this increase due to [illegible] chemical action while in the liquid.

The purest methyl alcohol obtainable in Chicago was then at 8-30 A. M. run into the dielectric tube and measurements begun. But with this liquid it was also found impossible to measure the resistance of the platinum thermometers, due presumably to the same cause as in the case of ethyl alcohol -- contact e.m.f. between the copper tubes and the liquid. In this case, however, the effect was greater even than with the ethyl alcohol, but the methyl alcohol was also subsequently found to be more of an electrolyte than the ethyl alcohol.

The specific resistance, i.e. resistance of 1 cu. cm., of the ethyl alcohol was 30,000 ohms: of the methyl alcohol was 1500 ohms. Sanford used "wood alcohol", but he says nothing about testing it for conductivity. Presumably, therefore his liquid had no conductivity. But owing to the fact that I could get no non-conducting methyl alcohol (several samples were tested) I can therefore give no results with this liquid. Even if the alcohol had not been otherwise tested, the following results prove clearly that the specimen used was an electrolyte. It had a slightly cloudy appearance after being run out of the tube

Observations on Effect of Methyl Alcohol. Dielectric. [illegible] Alcohol.

P_1 = 7.4000 at 22°
V_1 = 0.27806 " 21°8

P_2 = 7.33410
V_2 = 0.270605 } Air Values.

Date	Hour	T	T_1	T_2	R'	R"	[illegible]
	A.M.				Cm.		
Aug. 20	10-00	20°8	20°37	20°15	39	37.9	
	P.M.						
	12-15	21.0	20°45	20°38	42	40.8	
	2-15	21°0	20°5	20°42	42.5	41.	

The methyl alcohol was now run out, and without draining, the tube was closed and the following measurements taken

Date	Hour	T	T_1	T_2	R'	R"	
	P.M.				Cm.		
Aug. 20	4-30	21°0	20°55	20°5	56.0	53.0	
					55.6	53.	
					55.9	52.9	
	6-55	21.0	20.4	20.4	56.3	53.9	
					56.2	53.7	
					56.4	53.9	
					57.0	53.9	
					56.8		
					56.54	53.85	0.270690
					Pt.		
	7-15	"	"	"	3625	3320	
					3625	3320	
					3625	3320	7.30470

This value of V_2 is an increase of 0.00008 ohm, i.e. 0.03%, compared with the above given air value, but a decrease when compared with the following value in air, which value is 0.270698 when reduced to this temperature. This gives an apparent decrease of 0.014% due to methyl alcohol vapor.

The tube was now dried and freed of the methyl alcohol vapor and measurements for air made, and the increase in V_2 shows plainly that the methyl alcohol acted chemically upon the wire increasing its resistance.

Observations after Methyl Alcohol pumped out:-

Dielectric: Air. P_1 = 7.1000 at [illegible]° C
W_1 = 0.27506 " 21.[illegible]°
P_2 = 7.5000 at 20°5
W_2 = 0.276[illegible]5 " 20.4

These latter used in these calculations

Date	Hour	T	T_1	T_2	No.	R'	R"	R
	A.M.					Pt.		
Aug. 21	[illegible]-00	20°[illegible]	20.22	20.22		3540	3[illegible]4[illegible]	
					a	3540	32[illegible]	
						Cu.		
	[illegible]-10	"	"	"		5[illegible].5	54.[illegible]	
					1	56.2	54.4	
						56.3	54	
						56.7		
						Pt.		
	8-40	"	"	"	[illegible]	3540	3[illegible]40	
	11-50	20.8	20.35	20.35		3555	32[illegible]	
					c	3570	3270	
	P.M.					Cu.		
	12-2[illegible]	20.9	20.4	20.4		57.	54.4	
					2	57	54.5	
						57.1	54.4	
	2-1[illegible]	21°0	20.4	20.4		57.	54.[illegible]	
					3	57.1	54.7	
						57.1	54.7	
						Pt.		
	2-30	"	"	"		3550	3250	
					d	3545	3245	
						3545	3245	
	4-20	21°0	20.4	20.4	e	3550	3250	
						Cu.		
	4-45	"	"	"		57.	54.[illegible]	
					[illegible]	57.	54.[illegible]	
	4-[illegible]	"	"	"	f	[illegible]	[illegible]	
	[illegible]-45	21°3	20.4	20.4		3545	3250	
					g	3545	3245	
						354[illegible]	3245	
					Mean	355[illegible]	32[illegible]	[illegible]
						Cu.		
	7-00	"	"	"		57.	[illegible]	
					[illegible]	57	[illegible]	
						5[illegible]	[illegible]	
					[illegible]	[illegible]	[illegible]	0.[illegible]

Using value of P_1 [illegible] in the calculation [illegible] $_{1,2}$ [illegible] is [illegible].00[illegible]32 [illegible] less than value in methyl alcohol paper [illegible] corresponds to 0.05[illegible]. Similarly P_2 = [illegible] of W_1 at 21°[illegible] [illegible] $_2$ [illegible] as stated.

A few cc. of sulphuric ether were poured into the bottom of the tube and a little air blown through it to fill immediately the tube with the vapor. After allowing [illegible] that the two tubes would attain same temperature the following observations were made:-

Dielectric: Ether Vapor.

$P_1 = 7.5000$ $P_2 = 7.50[illegible]$ } in air
$W_1 = 0.27655$ $W_2 = 0.275183$ }

Date	Hour	T	T_1	T_2	No.	R'	R"	P
	A.M.					Pt.		
Aug 22	9-10	21.2	20.35	20.35		3555	3250	
					a	3555	3260	
						3555	3260	
						Cu.		
	10-10	21.2	20.38	20.33		57	54	
					1	56.6	54	
						56.7	54	
						56.[illegible]	54	

To make sure the tube was full of ether vapor, some more ether was run into the tube at 12-30, Aug 22".

Date	Hour	T	T_1	T_2	No.	R'	R"	P
	A.M.					Pt.		
Aug.23	8-30	21°0	20°27	20°27		3595	3285	
					b	3595	3285	
						Cu.		
	9-00	21°4	20.32	20.32		56.8	53.[illegible]	
					2	56.8	54.0	
						57.0	54.0	
						57.0	54.0	
						Pt.		
	10-20	21°5	20.4	20.4		3605	3290	
					c	3605	3300	
						3605	3300	
						Cu.		
	10-30	"	"	"		57.2	54.1	
					3	57	54	
	P.M.							
	12-30	21°7	20.48	20.47		57.0	54	
					4	57.0	53.8	
							54	
					mean	56.92	54.00	0.27[illegible]
						Pt.		
	12-35	"	"	"		3605	3300	
					d	3610	3305	
						3610	3300	
					mean	[illegible]10	[illegible]	7.50[illegible]

This is value of P_2 is an increase of 0.00017 [illegible] and corresponds to 0°012 C. Hence correcting [illegible] temperature the result gives a decrease of .000[illegible], as [illegible]

At 5-10 P.[illegible]. the [illegible] run in and out [illegible] the [illegible] ([illegible] found this necessary [illegible] the [illegible] drawing air through. The following observations were taken:-

Dielectric: Air

Date	Hour	T	T_1	T_2	No	D'	"	?
	P.M.					Cu		
Aug.23	5-05	22.5	20.6[illegible]	20.62		57	53.7	
						57	53.7	
						57		
	A.M.					Pt		
Aug.24	[illegible]-00	21.5	20.45	20.45		3630		
					a	3635	3325	
						3635	3325	
						Cu.		
	8-20	21.5	20.47	20.47		59	56	
					1	58.8	55.[illegible]	
						58.9	55.9	
	10-15	21.8	20.68	20.68		58.9	55.[illegible]	
					2	58.8	55.7	
						Pt		
	10-40	21.9	20.[illegible]8	20.68	b	3700	3420	
						Cu.		
	11-10	22.2	20.76	20.72		59	55.6	
					3	59	55.8	
						59		
						Pt.		
	11-25	22.2	20.77	20.75		3635	33[illegible]	
					c	3660	3340	
							3300	
	P.M.							
	1-00	22.4	20.78	20.78		3635	3330	
					d	3625	3325	
						3625	3320	
						Cu.		
	1-10	"	"	"		58.7	55.9	
					4	58.7		
	2-40	"	"	20.75		58.7	55.[illegible]	
						59.4	55.9	
						59.4		
						Pt.		
	3-00	"	20.77	20.74		3720	33[illegible]	
					e	365[illegible]	33[illegible]	
						3[illegible]60	3350	

Observations with Air Dielectric (continued)

Date	Hour	T	T_1	T_2	No.	R'	R"	R
	P.M.					Cu.		
Aug.24	3-25	22.94	20.77	20.74		58.7	55.[illegible]	
					5	58.[illegible]	55.[illegible]	
						58.7		
	3-55	22.95	20.78	20.77		58.7	55.8	
					6	58.5	55.6	
						58.9	56.	
						59.		
					Mean	58.85	55.82	0.2[illegible]222
						Pt.		
	4-10	22.95	20.78	20.77		3[illegible]60	3340	
					f	3650	3340	
						3655		
					Mean	3650	3340	7.3[illegible]40

Even correcting for temperature according to the platinum thermometer results this value is slightly greater than value obtained on 21st but the washing out with alcohol will account for it.

Some sulphuric ether was now again run in the dielectric tube and a little air blown through it in order to completely fill the tube with vapor. Then R' for Cu. immediately fell to 42, but it began immediately to increase.

Observations of following day:-
Dielectric: Ether Vapor.

Date	Hour	T	T_1	T_2	No.	R'	R"	R
	A.M.					Cu.		
Aug.25	7-55	21.95	20.40	20.40		58.6	55.6	
						58.6	55.[illegible]	
					1	58.6	56.1	
						58.	55.9	
						58.6		
	P.M.					Pt.		
	2-40	21.96	20.55	20.53	a	3630	3320	
						3630	3320	
						Cu.		
	3-00					59	[illegible]	
					2	59	56.	
						59	[illegible]	
							56.1	
						Pt.		
	3-30	21.[illegible]	20.60	20.60		3630	3320	
					b	3630	3315	

Observations with [illegible] (continued)

Date	Hour P.M.	t	t_1	t_2	No.	R'	R"	R
Aug. 25	4-00	22°0	20°60	20.60		3630	3512	
					c	3[illegible]30	3510	
						Cu.		
	4-10	"	"	"		59.0	56 1	
					3	58.8	56	
						58.6		
						Cu.		
	7-00	21°9	20.55	20.55		58.5	56	
						58.7	55.9	
						58.6	56 2	
					4	58.8	56.2	
						59.	56.3	
						58 8	56.2	
						Pt.		
	7-30	22°	20.58	20.58		3665	3550	
						3650	3545	
					d	3645	3540	
							3520	
	A.M.					3640	3540	
Aug. 26	7-45	21[illegible]	20.25	20.25		3640	3520	
						3635	3520	
					e	3620	3510	
						3620	3510	
						3620		
					Mean	3634	3524	7.36435
						Cu.		
	8-05	21.	20.26	20.26		58.9	56 [illegible]	
					5	58.9	56 2	
							56 1	
					Mean	58.8	56.04	0.27[illegible]

P_1 = 7.3800; W_1 = 0.27655

P_2 = 7.36440 } air values.
W_2 = 0.275222 }

This deduced value of P_2 in the vapor is less than the air value by 0.00004 ohm, which corresponds to 0.[illegible] [illegible]. Correcting W_2 for this temperature the result is [illegible] ohm greater than air value, an increase of 0.002.

Now as a result of these [illegible] tests of the effect of ether vapor I conclude that there was no effect. According to the copper measurement of the first test there was a decrease of 0.000003 ohm or less than 0.002 of one per cent. But assuming that the platinum thermometer indications were correct as measured in the two cases of air and vapor, a correction for temperature of 0.012° C had to be applied to the copper, making the decrease 0.00001 ohm or 0.006%. But according to the second test, the effect of the ether vapor was to increase the resistance about 0.002%, if temperature correction according to platinum thermometer be applied, or less than 0.001%, if we assume that no temperature correction need be applied. Now, under the conditions, it seems to me quite probable that no temperature correction need be applied in either case; for, standing side by side so long in the water jacket, the difference of temperature of the wires was certainly very small. Hence, according to these tests, the effect of the ether vapor may be said to be either nil or a change not greater than ± 0.002%.

The variations in R' and R'' are readily explainable by variable contacts of the bridge terminals and commutator, especially the latter; for variations in any one series will certainly be due to the commutator since nothing else was changed.

I [illegible] the two [illegible] results, for Sanford reported an increase of [illegible] to this dielectric of 0.2[illegible]

The tubes were now removed from the jacket in order to make some modifications and insert new copper coils. The old copper helices were removed and that in the dielectric tube was found to have a blackened surface while that in the air tube was still bright. This further proves that the alcohols had caused chemical action on the wire.

The new coils were made of #18 wire 72 feet of it being run off the spool, doubled at the middle, and polished with fine French emery paper. The wire was cut at the middle and each piece coiled on a 11/16" rod. The coils were then put in the tubes. These coils were made from wire obtained from the American Electrical Works, Providence, while the wire before used was made by Alfred Moore, Philadelphia.

A modification was made in the dielectric tube whereby the platinum thermometer was insulated from the tube containing it, the object being to secure measurements with the platinum thermometers of the temperature of liquids even though they might be electrolytes. The insulation was effected by inserting a piece of vulcanite rod, suitably bored out, between the copper plug [illegible] and the tube "[illegible]" (See Fig. 1, [illegible]

Fig.4) This change had the desired effect so far as measurement of the resistance of platinum wires was concerned, but a mistake was made of not making the same change in the air tube, which was left as originally designed. For the latter had a direct metallic connection through the cords, terminals, and plug H with the tube "h", and therefore with the whole of the interior of the air tube; while the dielectric tube, as now modified had the metallic connection broken through plug H and the tube "h". It was thought that this would make but a slight difference in the temperature of the two tubes, since the room temperature was in general but a degree or two at most above the temperatures of the tubes. Hence, being pressed for time, I did not stop to make the change in the air tube. But it was later found that this connection had considerable influence on the temperature of the tube, especially during the last three or four days of work when the weather became very warm. These temperature differences appear in the following record.

Fig 4.

The tubes were put back in the jacket and on ...

of Aug. [illegible] measurements were made with the [illegible]

Antho [illegible] of the insulation between the two tubes [illegible]

P_1 and W_1 .

Insulation resistance between the two tubes [illegible]

100 000.000 ohms

At 21°5, P_1 = 7.3805. platinum wire of air tube.

W_1 = 0.24150. resistance of air tube and its copper wire.

$W_1 - W_2$ = 0.00100 ohm; $P_1 - P_2$ = 0.0000 [illegible] metel i.e. 0.5% of P_1

Before, $P_1 - P_2$ = 0.0164 which was .55% of P_1 .

Comparison of the Copper Wires:-

R_1 = 7.9005 Temperature coefficients for Pt
r_1 = 0.24150

α = .0018. For this new copper wire α = .0030.

Dielectric: Air.

Date	Hour	T	T_1	T_2	No.	R'	R"
	A.M.					Cu.	
Aug. 29	9-10	23.8	21.10	21.01		54.2	52.00
						54.4	52.3
						54.1	51.9
						54.0	51.4
						53.9	51.5
						54.2	51.6
						Pt.	
	9-30	24.	21.15	21.05		6500	5600
						6490	5550
						6470	5570
						6470	5560
	P.M.						
	1-00	24.3	21.22	21.12		6430	5550
						6430	5530
						Cu.	
	1-10	"	"	"		54.0	51.00
						54.0	51.10
						54.0	51.4
	4-00	24.3	21.25	21.15		55.9	51.7
						54.2	51.4
						54.3	51.5
						Pt.	
	4-15	"	"	"		6450	5550
						6450	5570
	A.M.						
Aug. 30	8-00	23.0	20.9	20.86		6630	5630
						6650	5630
						Cu.	
	8-15	"	"	"		55.8	52.4
					1	55.7	52.7
						55.7	53.7
						Pt.	
	8-40	"	"	"	1	6570	5600

Dielectric: Air (continued).

Date	Hour P.M.	T	T_1	T_2	Co	R'	r	
						Pt.		
Aug.30	12-10	23.9	21.05	21.00		[illegible]	[illegible]	
					c	[illegible]	[illegible]	
						Cu.		
	12-20	"	"	"		56.2	52.4	
					2	55.6	52.3	
						55.1	52.5	
						55.5		
	2-15	23.2	21.13	21.08		55.5	52.	
						55	52.	
					3	55.4	52.1	
						55.5	52.5	
							52.3	
						Pt.		
	3-00	23.3	21.20	21.15		6730	5730	
					d	6720	5740	
	4-50	23.5	21.25	21.20		6740	5740	
					e	6730	5740	
						Cu.		
	5-00	"	"	"		55.6	52.3	
					4	55.4	52.3	
	7-00	23.6	21.22	21.17		55.6	52.3	
					5	55.5	52.5	
						55.6	52.4	
					mean	55.5	52.4	0.24[illegible]
						Pt.		
	7-10	"	"	"	f	6710	5740	
							5730	
					mean	6730	5770	[illegible]

*From mean of observations made on Aug.30th.

In these and subsequent measurements the sensibility of the galvanometer was less than with first pair of copper wires. The running of a large induction coil but 2 feet away in the adjoining room did the mischief. But the period of the galvanometer was not much affected. Now 1 ohm change in R' for copper caused deflection of 1[illegible]-18 divisions. In much of the preceding work the same resistance change caused [illegible] divisions deflection.

Comparison of [illegible] (continued)

Date	Hour	T	T_1	T_2	No.	R'	R"	[illegible]
	A.M.					Cu.		
Aug. 31	~~Hour~~ 8:00	22°6	20.[illegible]0	20.[illegible]0		56.4	53.[illegible]	
						56.6	53.4	
					1	56.6	53.4	
						56.6		
						Pt.		
	8-15	"	"	"		7500	6300	
					a	7500	6300	
						7480	6[illegible]	
	9-00	"	"	"		7470	6[illegible]0	
						7450	6[illegible]0	
					b	74[illegible]0	6250	
						74[illegible]0	6240	
					mean	7470	[illegible]270	[illegible]
						Cu.		
	9-20	"	"	"		56	52.[illegible]	
					2	56.2	52.9	
						56.1	52.9	
					mean	56.34	53.2	0.[illegible]

A little sulphuric ether was now run into the dielectric tube from the top to fill tube with vapor. The temperature of the tube immediately fell nearly 1°C below air tube, but in 25 min. its temperature rose to within 0.2° of air tube, according to Hg. thermometers.

Dielectric: Ether Vapor.

Date	Hour	T	T_1	T_2	R'	R"	[illegible]
	A.M.						
Aug. 31	11-45	22°6	21°10	21°02	55.0	52.0	
					55.0	52.0	
					Pt.		
	11-55	"	"	"	6950	5[illegible]10	
					6950	5[illegible]10	
					6950		
	P.M.						
	1-00	23°0	21.15	21.0[illegible]	6[illegible]70	5[illegible]	
					6960	5[illegible]20	
					Cu.		
	1-0[illegible]	"	"	"	55.0	52.[illegible]	
	5-05	23°2	21°1[illegible]	21.12	[illegible].0	[illegible]	

Observations on Ether Vapor (Cont).

Date	Hour	T	t_1	t_2	No.	R'	R"	[illegible]
	P.M.					Pt.		
Aug.31	3-10	23.92	21.1[illegible]	21.12		6[illegible]0	[illegible]	
						Pt.		
	4-30	23.5	21.22	21.16		6070	5840	
					a	6070	5840	
						Cu.		
	4-35	"	"	"		54.[illegible]	51.[illegible]	
					1	55.0	51.[illegible]	
	7-0[illegible]	23.5	21.24	21.18		55.0	52.1	
					2	5[illegible].2	52.0	
						55.1	52.1	
					mean	55.0	52.[illegible]	0.[illegible]
						Pt.		
	7-15	"	"	"		6900	58[illegible]0	
					b	6890	58[illegible]0	
						6870	5850	
							5860	
					mean	6[illegible]80	5860	[illegible]

P_1 = 7.3803 P_2 = 7.37232 } air
W_1 = 0.24150 W_2 = 0.240439 }

P_2 is here 0.00061 ohm less than in air, corresponding to 0°045 temperature difference. Correcting W_2 for this the result gives W_2 = 0.240454, an increase of 0.006[illegible] over air value.

Date	Hour	T	t_1	t_2	No.	R'	R"	[illegible]
	A.M.					Pt.		
Sept.1	8-00	21.8	20.77	20.77		7320	6160	
					a	7300	6160	
						7300	6140	
						Cu.		
	8-15	"	"	"		56.3	53.0	
						56.5	53.2	
						56.[illegible]	53.[illegible]	
						56.2	53.0	
						56.25	53.00	0.[illegible]
						Pt.		
	8-30					7210	6000	
						7210	6000	
					mean	727[illegible]	612[illegible]	[illegible]

Correcting W_2 for 0°.012 C, the platinum [illegible] indica- tion. the result is 0.24044[illegible], an increase of 0.005[illegible]. The change of 0.003[illegible] would be caused by a temperature difference of 0.00[illegible]°C.

Hence with two different wires these [illegible] show that if ether vapor produced any effect its percentage was one-fiftieth only that reported by Sanford. But since even this maximum effect, if any, is comparable to that produced by a temperature difference of .01° C., it is very doubtful if the vapor produced any effect at all. And that the tube was full of the vapor was shown by the fact that when the rubber tube was opened to free the dielectric tube of vapor, about 5 cc. of the liquid ether ran out. The tube was freed of vapor by blowing air through for fifteen minutes. Absolute (?) alcohol, the same kind as used before, was then used for washing the tube out. ~~(Sanford found this necessary to free the tube entirely of ether vapor)~~.

The tube was then filled with the alcohol as dielectric. The temperature of the tube was then somewhat higher than that of the air tube, as indicated by the thermometers and also by increased resistance of the dielectric tube and coil. But this temperature difference decreased and in three hours the temperature of the dielectric tube had fallen below that of the air tube. The resistances of both the copper and platinum wires proved this. At first R' for copper was [illegible] ohms; in a few minutes it fell to [illegible] ohms and in forty minutes to [illegible]. And when R' for copper was 60 ohms its value for platinum was infinity. In fact the resistance of the platinum wire in dielectric tube was greater than that of air tube

The object of trying again the effect of the alcohol was to make sure of my ground. The modification of the [illegible]. thermometer now made it possible to learn something of the temperature of the dielectric tube, and thus it became possible to study more closely the effect of the alcohol

Observations with Absolute(?) Alcohol [illegible]

P_1 = [illegible]036 W_2 = 0.[illegible] } air

[illegible]$_1$ = 0.241[illegible]0 $\log P_2$ = [illegible].37[illegible]

Date	Hour	T	T_1	T_2	No.	P'	P"	[illegible]
	P.M.					Pt.		
Sept. 1	12-45	23°		21°13		6750	5770	
						6750	5770	
						Cu		
	12-[illegible]	"		"		53.4	50.4	
						53.4	50.[illegible]	
	3-00	23°2	21.15	21.07				
						54.3	51.[illegible]	
						54.5	51.0	
						Pt.		
	3-15	23.2	"	"		7050	6000	
							5970	
	4-20	23°5	21°23	21°11		6910	58[illegible]0	
						6910	5820	
						Cu.		
	4-30	23°5	"	"		54.0	51.0	
						54.3	51.4	
						54	51.0	
	[illegible]-[illegible]	23°4	21°20	21°10		54.5	51.[illegible]	
						54.5	51.[illegible]	
						Pt.		
	7-10	"	"	"		6[illegible]70	59[illegible]0	
						6[illegible]40	5920	
						6[illegible]50	5900	
	A.M.							
Sept. 2	7-55	23°2	21°03	20°03		7120	605[illegible]	
					a	7120	[illegible]020	
	8-05	"	"	"		[illegible]5.8 Cu.	53.0	
					1	55.[illegible]	52.1	
						[illegible].5	52.[illegible]	
	9-35	23°2	21°10	21°00		55.5	51.[illegible]	
					2	55.5	[illegible]2.5	
						55.5	52.5	
						Pt.		
	9-[illegible]0					[illegible]70	[illegible]10	
					[illegible]	[illegible]40	5900	
	11-35	23°4	21°17	20°07		[illegible]70	5[illegible]	
					c	[illegible]70	[illegible]	

Observations with Absolute(?) Alcohol (Continued) ([illegible])

Date	Hour	T	T_1	T_2	[illegible]	[illegible]	"	[illegible]
	A.M.					C.		
Sept.2	11-45	23.94	21.17	20.07		55.3	52.5	
					3	55.3	52.2	
						53.75	52.3	0.[illegible]
						Pt.		
	11-55	"	"	"		6960	5120	
					d	6960	5120	7.5[illegible]

This value of P_2 is 0.00052 ohm less than air value, and corresponds to 0.04C.

Making the corrections of W_2 for 0.04°C there is obtained W_2 = 0.240459, which is 0.000020 greater than in air, which is an increase of 0.008%, possibly due to the alcohol. But, as stated before, this alcohol was a slight conductor, i.e. an electrolyte, and as before, it probably dissovled away some of the copper wire, making its reistance greater. This increase is seen when the air values of Sept. 4th and 5th are compared with those of Aug. 31st, and comparing the values resulting from measurements in alcohol with these latter air values there is a decrease of nearly 0.006% apparently due to the alcohol. But this apparent decrease is readily explained by the conductivity of the alcohol. Hence that there was any increase due to alcohol, aside from mere chemical effects, seems, in the light of these tests, very improbable.

These measurements with alcohol [illegible] very difficult to make. The thermal currents in the galvanometer circuit [illegible]

quite strong at times, amounting at one reading to a deflection of 12 cm. Hence, though the galvanometer circuit would be broken but for one instant while the battery circuit was being closed or broken, as the case might be, the movement of the needle was still considerable. The presence of the alcohol acted just as if self-induction were introduced into the circuit, i.e. the "throw" of the galvanometer needle, provided the galvanometer circuit were closed, on closing the battery circuit, was similar to that caused by self-induction. This "throw" when the copper resistances were connected to the bridge, varied from one to three cm., though it was zero cm. when air filled the dielectric tube, and the modification previously made in the platinum thermometer proved effectual in preventing this "throw" when the platinum wires were connected to the bridge

The alcohol was now run out, and the tube freed of its vapor by drawing and blowing air through for 5 minutes.

The tube was next filled with gasoline and the liquid run out, the top of the tube being closed as originally, and the bottom closed as soon as the liquid ceased flowing. The object was to fill the tube with gasoline vapor and air. Prof. Sanford found a marked effect with gasoline vapor gas.

The following observations were then taken:

P_1 = 7.3603 P_2 = 7.37152 } air values of Aug. 31" before
V_1 = 0.24150 V_2 = 0.240439 } alcohol was in tube.

Dielectric: Gasoline Vapor

Date	Hour P.M.	T	T_1	T_2	No.	R'	R"	R
						Cu.		
Sept.3	12-25	23.1	21.20	21.10	1	58.5	55.0	
						58.5	54.6	
						Pt.		
	12-35	"	"			7610	6390	
					a	7590	6360	
	2-40	23.3	21.19	21.12		7650	6390	
					b	7640	6400	
						Cu.		
	2-50	"	"	"		58.3	55.0	
						58	54.5	
						Pt.		
	3-10					7530	6370	
					c	7560	6370	
						Pt.		
	3-30	23.4	21.22	21.14		7580	6360	
					d		6350	
						Cu.		
	3-40	"	"	"	3	58.3	54.[illegible]	
						Pt.		
	3-45				e	7560	6530	
	9-25	23.4	21.20	21.12		7570	6350	
					f	7560	6350	
						Cu.		
	9-32	"	"	"		57.4	55.0	
					4	58.2	54.6	
						58.3	54.6	
					Mean	58.2	54.6	0.[illegible]
						Pt.		
	~~9-45~~	"	"	"	Mean	7570	6370	[illegible]

This is for P_2 an increase of 0.00012 over air value and gives 0.01°C. Correction V_2 is 0.0000[illegible] [illegible] air, a decrease of less than 0.002[illegible].

Further observations with alcohol Vapor.

Date	Hour A.M.	T	I_1	I_2	d.	'	"	[illegible]
						Pt.		
Sept 4	6-40	23°	21°01	21°00		7580	65.0	
					a	7910	6560	
						Cu.		
	7-00	"	"	"		59.4	55.2	
					1	59.5	55.3	
						59.4	55.	
						Pt.		
	7-15				b	7950	6610	
	8-30	22°4	20.80	20°80		7920	6560	
					c	7900	6560	
						Cu.		
	9-05	22°4	20.85	20.85		59.5	55.3	
					2	59.3	55 1	
						59.2	55 3	
					mean	59.4	55.3	0.9404
						Pt.		
	9-25				d	7970	6630	
					mean	7905	6570	1.3726

Corrected for 0°.05 C. the value of I_2 is 0.007 greater than in air.

Tube now exhausted of vapor and following observations for air taken; the exhausting continued 40 minutes.

Observations after Cooling Vapor Pumped out:-

Dielectric: Air.

Date	Hour	T	T_1	T_2	No.	R'	R"	R	
	A.M.					Pt.			
Sept 4	10-20	22°8	21.20	21°15		7840	6510		
						7860	6520		
						Cu.			
	10-35	"	"	"		59.0	55.4		These not
						59.0	55.1		counted in
	P.M.								average.
	2-40	23.0	21°20	21°14		59.	55.2		Tubes could
						59.	54.3		not stand
						Pt.			long without
	2-50					7600	6360		either ex-
						7600	6370		hausting
									the vapor.
	3-50	23°0	21°25	21°18		7560	6340		
						7570	6350		
						Cu.			
	4-00	"	"	"					
						59.0	55.3		
						58.8	54.7		
						58.7	54.5		

Commutator freshly amalgamated.

Date	Hour	T	T_1	T_2	No.	R'	R"	R
	P.M.							
	7-00	23°4	21°30	21°23		58.5	55.4	
					1	58.5	55.4	
						Pt.		
	7-10	"	"	"		7540	6340	
					a	7540	634[illegible]	
	9-25	23°5	21°35	21°28				
						7590	6370	
					b	7590		
						Cu.		
	9-35	"	"	"		58.5	55.3	
					2	58.3	55.3	
						58.3		
					mean	58.5	55.35	0.240479
						Pt.		
	9-45				c	7590	6370	0.2[illegible]

$R_1 = 7.5503$; $T_1 = 0.24150$

Corrected for 0°01, T_2 is 0.24040[illegible]

Observations after Gasoline Vapor pumped out ([illegible])

Dielectric: Air

Date	Hour A.M.	T	T_1	T_2	No.	P'	P''	[illegible]
						Pt		
Sept. 5.	7-20	22.8	21.13	21.10		7810	6550	
					a	7810	6530	
						Cu.		
	7-30	"	"	"	1	59.0	56	
						59.0	55.[illegible]	0.[illegible]
						Pt.		
	7-40	"	"	"	b	7780	6500	
	9-05	22.9	21.20	21.18	c	[illegible]0	[illegible]70	
						Cu.		
	9-12	22.9	"	"		59.[illegible]	55.3	
					2	58.[illegible]	55.7	[illegible] 57.[illegible]
						Pt.		
	9-20				d	7720	6440	
	11-15	23.0	21.30	21.25	e	7670	6410	
	11-22	"	"	"	3	58.6	55.5	
	11-30	"	"	"	f	7580	6380	

These values of P_2 and W_2 are used as standards in subsequent comparisons. This value of P_2 is 0.00015 ohm greater than that obtained on Sept. 4th, and corresponds to 0.01 C.

Hence from the results of Sept. 4th and 5th obtained with air dielectric, it is seen that exactly the same resistance for the dielectric tube and its wire is obtained, if the observed values are corrected by the platinum thermometer results. Otherwise, assuming that the same temperature difference existed on the afternoon of Sept. 4th as did on the morning of the 5th, there is a difference of 0.000003 ohm which is the amount that .01°C increases W_2. [illegible]

showing [illegible] that the platinum wires [illegible] to be nearer together in temperature than the evening before. The mercury thermometers show plainly that a difference in temperature nearly always existed at the top of the tubes, if no where else, and this was undoubtedly due to the modification made in the dielectric tube platinum thermometer, previously spoken of. whereby it became nearly thermally insulated from the outside while the Pt. thermometer of the air tube was not so well cut off from outside heat. For before this change was made, the two tubes on standing would always assume the same temperature as indicated by the same two mercury thermometers.

Now these last air values compared with those obtained on Aug. 31st, show that the alcohol had a slight chemical action on the wire, slightly increasing its resistance as it did in the two cases before. And the resistance in gasoline vapor, compared with the former air value, was <u>increased</u> according to measurement of Sept. 4th about 0.007%. But compared with these last air values, making temperature correction according to the platinum thermometers, there was a <u>decrease</u> of 0.014%, according to measurements Sept. 3rd, and 0.005% according to measurements of Sept. 4th. But if there be assumed to be the same temperature difference between the copper wires on Sept. 4th in the gasoline vapor as on Sept. 5th in air, (i.e. neglecting platinum thermometer indications)

Than the resistance of the dielectric tube [illegible] de-
[illegible] practically the same on the 3rd day. [illegible]
in the most unfavorable light according to these measurements,
the maximum effect that might be due to the vapor was [illegible] de-
crease. But this was according to measurement on the after-
noon of Sept. 3rd. a few hours after the gasoline was run in the
tube, and possibly ~~after~~ before the platinum wires had assumed the
temperature of the liquid outside. The measurements of the [illegible]"
are likely to be more reliable, for, after standing all night,
the Pt. wires were more likely to be at the temperature of the
surrounding medium. Hence, compared with the air value before
the alcohol had stood in the tube, the gasoline vapor might
have affected the resistance by 0.007%; compared with the air
value of Sept. 5th the possible effect was -0.005%. Sanford
found an effect of [illegible].17% increase with his laboratory burning
gas - mixture of gasoline vapor and air.

After the above measurements with air as dielectric,
"petrolic ether", a light benzine, was run into the tube. San-
ford used "benzine", and "petrolic ether" is rectified benzine
and therefore more likely to be pure than the ordinary benzine
of the stores.

According to the mercury thermometer, the "petrolic
ether" when first run in made the temperature of the dielectric
tube 0.8 lower than that of the air tube. This fall was probab-
ly due to volatilization, for the temperature of the liquid was
1.5 higher than that of the air tube, before being run in. [illegible]
measurement for [illegible]" with copper gave the value [illegible]

value, however, rose rapidly. But at no time [illegible] apparent "induction effect" on the galvanometer, producing a "throw" of the needle, as was the case always with alcohol. But such effects were observed only in those cases where the liquids, like methyl and ethyl alcohols, were not true dielectrics.

At 1-15 P.M. R" for copper was 45 ohms and temperature as per mercury thermometer was nearly 0.3°C below that of air tube. At 2-30 R" = 52 ohms. Other readings follow:

Observations for Effect of "Petrolic Ether".

Date	Hour P.M.	T	T_1	T_2	No	R'	R"	P
						Cu.		
Sept. 5	3-55	23°4	21°15	20°95		55.7	52.6	
						55.2	52.2	
						55.2	52.6	
						Pt.		
	4-05	"	"	"		6590	5660	
	5-45	23°5	21°16	20°98		6600	5670	
						Cu.		
	5-50	"	"	"		55.5	52.[illegible]	
						55.5	52.5	
	9-55	23°4	21°14	20°94		56.0	53.0	
						Pt.		
	10-03	"	"	"		6650	5710	

$$\left.\begin{matrix} P_1 = 7.3805 & P_2 = 7.37256 \\ W_1 = 0.24150 & W_2 = 0.240488 \end{matrix}\right\} \text{air.}$$

Observations for Effect of "[illegible]" (Con.)

Date	Hour A.M.	T	T_1	T_2	No.	R'	R"	P
						Cu.		
Sept. 6th	6-45	23°0	21.02	20°60		55.[illegible]	52.[illegible]	
					1	55.5	52.0	
						55.0	52.0	
						Pt.		
	7-00					6710	5740	
					a	6700	5730	
	9-20	23°0	21.10	20°88		6750	5760	
					b	6750	5770	
						Cu.		
	9-27	"	"	"		56.0	53.0	
						56.0	53.0	
					2	55.[illegible]	52.[illegible]	
					mean	55.80	52.[illegible]0	0.[illegible]
						Pt.		
	9-40	"	"	"		6730	5750	
					c	6710	5740	
						6700	5730	
					mean	6734	5750	[illegible]

This value of P_2 is 0.00104 less than air value [illegible] gives 0°0[illegible]C. Correcting, P_2 = 0.240500, an increase of [illegible].00[illegible] over air.

Prof. Sanford found that [illegible] increased the resist[illegible] 1,00[illegible].

The liquid was now run out and the following obtained:-

Observations for [illegible] of P[illegible] [illegible] Vapor:-

Date	Hour	T	T_1	T_2	No.	R'	R"	[illegible]
	A.M.							
Sept.6.	11-10	23°5	21.20	21.10		55.7	52.7	
						Pt.		
	11-17	"	"	"		6950	5920	
						6970	5920	
						Cu.		
	11-27					56.5	53.0	
						56.6	53.0	
	P.M.							
	12-40	23°7	21.25	21°17		57.0	53.8	
						57.1	54.0	
						Pt.		
	12-45	"	"	"		7180	6090	
						7180	6090	
"	2-15	23°8	21°26	21°19	a	7310	6200	
						Cu.		
	2-22	"	"	"		57.7	54.6	
					1	57.8	54.6	
						57.7		
						Pt.		
	2-35				b	7310	6170	
	6-40	23°8	21°29	21°20	c	7450	6280	
						7450	6280	
						Cu.		
	6-50	"	"	"		58.0	54.6	
					2	57.8	54.7	
						57.9	54.6	
						Pt.		
	7-00	"	"	"		7390	6240	
					d	7380	6250	
	10-10	24°0	21.40	21.30		7390	6250	
					e	7390	6250	
						Cu.		
	10-15	"	"	"		57.9	54.6	
					3	57.6	55.0	
						57.5	55.0	
	10-30				mean	57.66	54.70	[illegible]
						Pt.		
	10-30					7390	[illegible]	
					f	7390		
					mean	[illegible]	[illegible]	[illegible]

Corrected for 0.01° C, k_2 = 0.240452 [illegible],
a decrease of 0.0025 from air value.

The "petrolic ether" vapor [illegible] now at 10-40 P.M. pumped out, the {forcing / drawing} of air through the tube lasting only an hour. T[illegible]

The next day the following observations were made:-

P_1 = 7.3803 P_2 = 7.37250 } [illegible] values of Sept. [illegible]
W_1 = 0.24150 W_2 = 0.24048 }

Dielectric: Air.

Notice that temperature rose quite rapidly as the morning advanced. The day proved to be the hottest for a month.

Date	Hour	T	T	T	No.	R'	R"	R
	A.M.					Cu.		
Sept.7	9-50	23°5	21°25	21°18		57.6	54.7	
						58.	54.9	
						58.	54.9	
						Pt.		
	10-00	"	"	"		7390	6240	
						7380	6250	
	10-52	23°8	21°38	21°30		7350	6200	
						7350	6200	
						Cu.		
	10-5[illegible]	"	"	"		657.9	5[illegible]	
						57.9	54.7	
	P.M.					Pt.		
	12-4[illegible]	24°	21°43	21°32		7300	6160	
						7290	6100	
						Cu.		
	12-57	"	"	"		57.0	54.2	
						57.0	54.0	
						Pt.		
	1-05					7270	6150	
	2-45	24.3	21°50	21.35		7250	6140	
						7250	6140	
						Cu.		
	2-55	"	"	"		57.5	54.4	
						57.5	54.5	
						57.5	54.[illegible]	
						Pt.		
	3-05					7250	6150	
						7250	6150	
	3-15	24.4	21.47	21.[illegible]		7210	[illegible]	
						7210	6150	

Date	Hour	T	T_1	T_2	No.	R'	R"	[illegible]
	P.M.					Cu.		
Sept. 7	5-35	24.4	21.47	21.53		[illegible].0	5[illegible]	
						57.1	54.0	
	[illegible]-45					[illegible]190	60[illegible]0	
						71[illegible]0	60[illegible]0	
	6-25	24.5	21.54	21.4[illegible]		7250	[illegible]120	
						7220	6120	
						Cu.		
	6-55					57.0	54.1	
						57.0	54.0	
	11-55	24.3	21.20	[illegible]1.1		57.4	54.2	
						57.4	54.3	
					mean	57.4	54.[illegible]	.2[illegible]
	A.M.					Pt.		
	12-04					7270	6150	
						72[illegible]0	6150	
					mean	72[illegible]6	6147	7.3[illegible]214

Here T_2 is 0.000028 o[illegible] less than air value, [illegible] exactly the same when corrected for C.O32, according to the Pt. thermometer indications.

[illegible] cc. of chloroform [illegible] into the dielectric tube drop by drop so as to fill the tube with its vapor. The [illegible] following [illegible] readings were [illegible]:-

P_1 = 7.3[illegible]03 W_2 = 0.2[illegible]04[illegible]5 } air.
W_1 = 0.2[illegible]150 P_2 = 7.57[illegible] }

Dielectric: Chloroform Vapor.

Date	Hour	T	T_1	T_2	No.	R'	R''	[illegible]
	A.M.					Pt.		
Sept. 8	[illegible]-55	23°[illegible]	21.07	21°00		7[illegible]0	[illegible]150	
						72[illegible]0		
						Cu.		
	[illegible]-0[illegible]					57.5	54.2	
						57.4		
	A.M.					Cu.		
"	[illegible]-00	24°[illegible]	21°3[illegible]	21.14		56.7	53.7	
						56.[illegible]	53.[illegible]	
						Pt.		
	9-08					[illegible]090	[illegible]050	
						70[illegible]0	[illegible]020	
	1[illegible]-00	24°5	21°47	21°3[illegible]		7030	[illegible]9[illegible]0	
						[illegible]030	[illegible]960	
						Cu.		
	1[illegible]-15					[illegible].3	53.[illegible]	
						56.2	53.4	
	P.M.							
	12-[illegible]0	25°	21°60	21°[illegible]0		56.1	53.4	
						5[illegible].2	53.2	
							53.2	
						Pt.		
	1[illegible]-5[illegible]					69[illegible]0	[illegible]920	
						6940	59[illegible]0	
	3-20	25°4	21°82	[illegible]1°70		6[illegible]0	[illegible]0	
						6[illegible]10	[illegible]0	
						Cu.		
	3-30					[illegible]6 0	[illegible]	
						5[illegible]	[illegible].0	
						5[illegible]	[illegible]	
						5[illegible].24	5[illegible].3	0.[illegible]

Date	Hour P.M.	T	T_1	T_2	'	"	
Sept [illegible]	5-42				[illegible] 0	[illegible]	
					67·0	5100	
					[illegible]	[illegible]	[illegible]

Correction [illegible] for 0.0[illegible] its value is [illegible].00000[illegible] [illegible] greater than in air, an increase of nearly 0.002%.

Sanford's value was 0.15% increase.

The vapor was now pumped out and, the tube was certainly full of vapor for about 10 c.c. of chloroform ran out when the tube was opened.

But the rubber discharge tube of the dielectric tube having become stopped, the latter was removed from the jacket, necessitating a break in the electric connections. The rubber tube was cleared and the copper tube replaced in the jacket. The tube was then filled at 6-00 P.M. Sept. [illegible], with Squibb's absolute ethyl alcohol of 99.[illegible]% and a series of measurements made. The result of these showed an increased resistance, apparently due to the alcohol, of nearly [illegible].02% when compared withe the former air values. But the dielectric tube had been removed from the water jacket and some of the electrical connections broken since the air values were obtained. But after the measurements in alcohol, another series of measurements in air were taken, and compared with the latter results, the alcoholic effect, if any, was about +0.002%.

During the last four or five days of measurements the weather has become very warm - the warmest since the measurements began - and the effect is seen in the temperature observations. But, notwithstanding these temperature differences, the resistances of the copper seem to be constant when corrected according to the platinum thermometer indications. The results may be considered proof of the reliability of the platinum thermometers.

The Squibb's absolute alcohol was a better dielectric than the alcohol used before, its specific resistance being 90,000 ohms while that of the other was 30,000 ohms. This fact was further shown also by the smaller "throw" of the galvanometer needle on closing the battery circuit when the copper resistances were attached to the bridge. With the other alcohol this "throw" amounted to 2 - 3 cm. With this sample it was only 2 - 3 mm. In kerosene, petrolic ether, and the vapors, this "throw" was zero. This was the most absolute alcohol obtainable in Chicago. I tried it because it was a better dielectric than the alcohol used before, and I desired to know the effect it might produce.

Observations on Effect of Sq[illegible] in Absolute Alcohol.

P_1 = 7.50030 P_2 = 7.57[illegible]6 } former air values.
W_1 = 0.24150 W_2 = 0.240[illegible] }

But true comparison air values are those on following page.

Date	Hour	T	T_1	T_2	No.	R'	R"
	P.M.					Cu.	
Sept. 8	9-55	21°95	21°5[illegible]	21°02		55.7	52.9
						56.	52.6
							53.0
	10-05					55.6	52.5
						55.5	52.5
						Pt.	
	10-15					6070	5300
						6050	5270
	A.M.					Pt.	
Sept. 9	6-40	25.0	20°94	20°62		6090	5300
					a	6070	5280
						Cu.	
	6-55				1	54.7	51.7
						54.7	51.8
						Pt.	
	7-05				b	6090	5290
	8-35	24°9	21°00	20°65	c	5930	51[illegible]0
						5930	51[illegible]0
						Cu.	
	8-45					54.0	51.3
					2	54.0	50.9
						Pt.	
	9-55					5900	5150
					d	5900	5150
	10-45	25°	21°12	20°77		5930	51[illegible]0
					e	5910	5160
						Cu.	
	11-00					54.2	51.3
					3	54.0	51.0
						54.0	51.0
						Pt.	
	11-1[illegible]	2[illegible].3	21°20	20.80		5870	5150
					f	5870	5150

Date	Hour P.M.	T	T_1	T_2	No.	R'	R"	P
Sept. 9	12-4[illegible]	[illegible]3	21.[illegible]0	20.[illegible]		[illegible]0	5[illegible]10	
					6	[illegible]0	5[illegible]10	
						Cu.		
	12-55					54.6	51.6	
					4	54.6	51.7	
						Pt.		
	1-05					5[illegible]0	5200	
					[illegible]	5960	5190	
						5960	5195	[illegible]
						Cu.		
	1-15					54.7	51.7	
					5	54.5	51.0	
						54.3[illegible]	[illegible]1.3[illegible]	0.[illegible]40[illegible]01

On the afternoon of the 9th, the alcohol was [illegible] out of the tube, the latter dried, and the next morning the following observations with air as dielectric taken:-

P_1 = 7.3803
W_1 = 0.24150

Dielectric: Air.

Date	Hour A.M.	T	T_1	T_2	No.	R'	R"	P
						Cu.		
Sept. 10	6-40	25°	20.60	20.26		56.3	53.0	
					1	56.4	53.0	
						56.6	53.3	
						Pt.		
	6-55					6520	5650	
						6520	5650	
						Cu.		
	[illegible]-05					56.9	53.3	
					2	57.0	53.3	
	8-25	2[illegible]°	20.75	20.32		57.3	54.0	
					3	57.3	54.0	
						57.0		
						5[illegible].85	53.[illegible]0	0.[illegible]04[illegible]
						Pt.		
	[illegible]-40					[illegible]530	5[illegible]50	
						6530	5650	
						65[illegible]	5[illegible]	.3[illegible]

If the values obtained with alcohol, as [illegible] on the preceding page, are compared with these values for air - and it is with these values they should be compared, owing to the

ured in connections previously [illegible] - the value for Pt_2, or R_2, is less than unit by 7.37130 - 7.37085 = 0.00045 ohm, which is equivalent to 0.054° C. Correcting 0.24040 for this temperature, there is obtained V_2 = 0.240400 ohm for alcohol, which is greater than the value for air by 0.000005 ohm, i.e. 0.002%.

This closed the work of ~~the~~ observation on the effect of the dielectrics. And according to the tests made none of the alcohols employed were good dielectrics. Professor Sanford said nothing about testing his alcohols, or other liquids, to determine their conductivity. It seems probable that he did not make these tests, else he certainly would have dropped a word concerning the necessity of purity of the liquid dielectrics or their varying conductivity. I used the best alcohols I could get on the market in Chicago, obtaining them from the same dealers who supplied the chemical laboratory of the University of Chicago.

Now while the preceding observations show some variations among themselves, still the method was such that the shunt resistances of both the copper and platinum wires could vary considerably without any marked effect on the result. However, measurements of the same thing at different times agree to a few thousandths of one per cent. This proves that the method is one capable of giving results to a considerable de-

free of mercury. In this respect I think it has considerable advantage over either Sanford's or [illegible]'s. I was not acquainted with the method employed by Signori Grimaldi and Platania at the time, not having access to their paper until a year after the foregoing observations were made. But in some respects my method is also superior to theirs.

I have reported the preceding observations in detail, with such variations as there may be, in order that some opinion may be formed as to the worth and reliability of results.

As a summary I give a table of comparisons between Sanford's results and my own. Sanford's results are for copper wire called C_1 (Phys. Review Vol. III, page 173).

I may name my first wire C_1 and the other C_2 .

TABLE OF COMPARISON

Dielectric	Sanford.	Merrill		P.
Kerosene	-0.18%	C_1 +0.002%		49-50
Absolute Alcohol	+0.15%	C_1 { -0.001% 1st test		57
		-0.001% 2nd test		62
		C_2 { +0.003% 1st sample	(1)	83
		+0.002% Squibbs'		100-1
Absolute Alcohol vapor	+0.05%	C_1 +0.01% 1st test	(2)	57-8, 57'
		-0.009% 2nd test		63-64
Methyl alcohol	+0.002%	C_1 ? ?? 1st test	(3)	65-6
		? ? 2nd test		
Ether vapor	+0.25%	C_1 -0.006% 1st test		68
		+0.002% 2nd test		71
		C_2 +0.003%		79
Gasoline vapor	+0.17%	C_2 +0.007% or -0.005%	(4)	86-90
Benzine (petrolic ether)	+0.06%	C_2 +0.005%		92
Benzine vapor	------	C_2 -0.002%		93
Chloroform vapor	+0.15%	C_2 +0.002%		96-7

(1) Possibly an effect of +0.002%, but not probably. (See [illegible].

(2) These effects, according to measurements are possible, but not probable. On pages 57' and [illegible] will be found my reasons for thinking that, according to my measurements, the effect, if any, of alcohol vapor was less than 0.001% in each of these two tests. My reason, briefly stated here, is that the alcohol was an electrolyte and that the [illegible]

wire was chemically acted upon while immersed in the alcohol, its resistance being permanently increased thereafter. And these results were obtained by comparison with the values in air before the alcohol was run in. If the results in the vapor were compared with those for air after the vapor was pumped out, the difference is less than 0.001%. And there can be no question but that this last comparison is the only legitimate one.

(3) The methyl alcohol used was so strongly an electrolyte that no comparison could be made.

(4) The effect for gasoline vapor of +0.00[illegible]% is obtained by comparing with air value before the absolute (?) alcohol was run in. This being the same sample as used before, it acted upon the wire, permanently increasing slightly its resistance. And the test in gasoline vapor was made after the alcohol was run out and before another value in air was obtained. But after the effect of the gasoline vapor was tested, then a comparison with air, as dielectric, was made. And comparing the gasoline effect with this last air value the percentage effect -0.005% is obtained.

Now, granting that Professor Sanford's results are due from real effects, still my results show that there is at present no "necessary modification of Ohm's law" needed, in which a factor is introduced to account for the influence of the di-

electric, provided indeed that the medium is a true dielectric. For in every case of a non-electrolytic medium results show no effect within the limit of experimental error. And I think the results will justify the conclusion that the experimental error was certainly no greater than 0.01%, since in no case do successive measurements under the same conditions give results that differ by 0.01%. In fact the agreement is much closer than 0.01%.

However, with a few modifications, the method is capable of giving still more accurate results. To this end it would be easy to provide a separate bridge for the copper resistances and the platinum thermometers, thus obviating the necessity of changing any of the bridge terminals.

The platinum thermometer could also be improved by getting some of Mr. Griffiths' thermometer wire, the temperature coefficient of which is about twice that of the wire I used. But I used the purest platinum wire I could get in this country. After three weeks of diligent inquiry Mr. James W. Biddle of Philadelphia said he could get no better wire for me this side of England. With the better wire the sensitiveness of the platinum thermometer could be increased in either one of two ways: (a) using half the length of wire, the resistance could be determined more accurately, a low resistance galvanometer being used; or (b) using the same length of wire as before the same temperature difference would produce a greater

change in resistance.

Again, if all the measurements are wholly conducted the commutator of the bridge might be dispensed with and only the battery commutator be employed. This would do away with the changing of any of the contacts in the circuit. But I think there would be little interest in pushing these measurements to the utmost limit of accuracy, since the measurements I have made show that at least in the case of coiled iron the dielectric - provided it is a true dielectric - causes a change less than 0.01%, if indeed it causes any change at all. And my object was to see if the effects found by Sanford really resulted in all cases and to the amount he reported. My results show no effects within a limit smaller than he could detect changes with his apparatus. And so far as Lehmann is concerned, the same remark applies to the apparatus of Mess. Grimaldi and Platania.

But Sanford and the Italian physicists obtained effects using a straight wire, while I employed a coiled wire. Sanford also tried to use a coiled wire but found his method of measuring resistance and temperature was not delicate enough to enable him to separate temperature effects from possible dielectric effects. He also expressed the belief that the influence of the dielectric depended somewhat on the amount of the surface exposed, and that a modification of Ohm's law was necessary in view of his results. Now Ohm's law applies to a

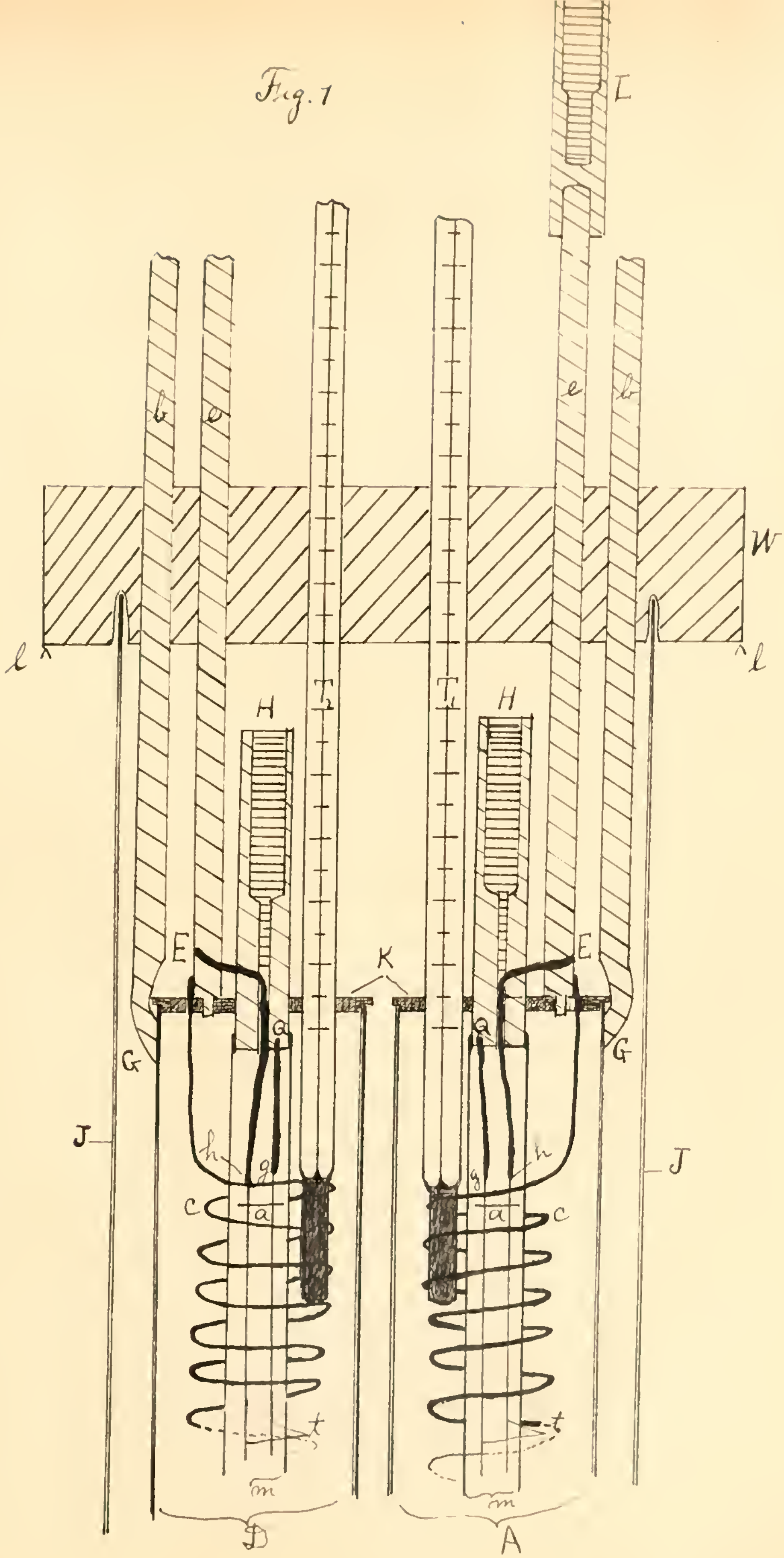
steady current in a coiled wire as well as to one in a straight wire. My purpose then was to try the case of coiled wires, in which he failed, thus getting a larger surface - I had nearly ten times more surface than he did - and to put his conclusions to a test. How well I succeeded in my purpose the foregoing results will show.

Drs. Grimaldi and Platania used such a short wire - about a foot long - that it seemed to me that they could not give Sanford's conclusions a fair test,—notwithstanding the results seemed to show a slight effect due to the dielectric,—especially since they tried but one dielectric while Sanford tried about fifteen. But of their work I have already spoken and it is unnecessary to add here anything further.

In conclusion I desire to express to Professors Rowland and Ames my thanks for the kindly interest they have taken in my work; and to Professors Michelson and Stratton for extending to me the privileges of the Ryerson Physical Laboratory where the measurements recorded in the foregoing pages were made.

Joseph Francis Merrill was born in Richmond, Utah, in the year 1868. He attended public and private schools in his native town, and the Normal School of the University of Deseret, (now University of Utah) graduating in 1889. He then entered the University of Michigan from which he received the degree of B. S. in 1893. The same year he was appointed Assistant Professor of Chemistry in the University of Utah, where he taught the following two years, devoting part of his time the second year to physics. Securing a leave of absence he entered Johns Hopkins University in 1895 as a student in physics, electing applied electricity and mathematics as subordinate studies. He returned to Utah in 1897, having been elected to the chair of Physics and Physical Chemistry in April of that year. But in the following year he secured another leave of absence, and returned to Johns Hopkins University as a Fellow in Physics. He studied at Cornell University during the summer term of 1893, and at the University of Chicago during the summers of 1894, '96 and '97.

Fig. 1



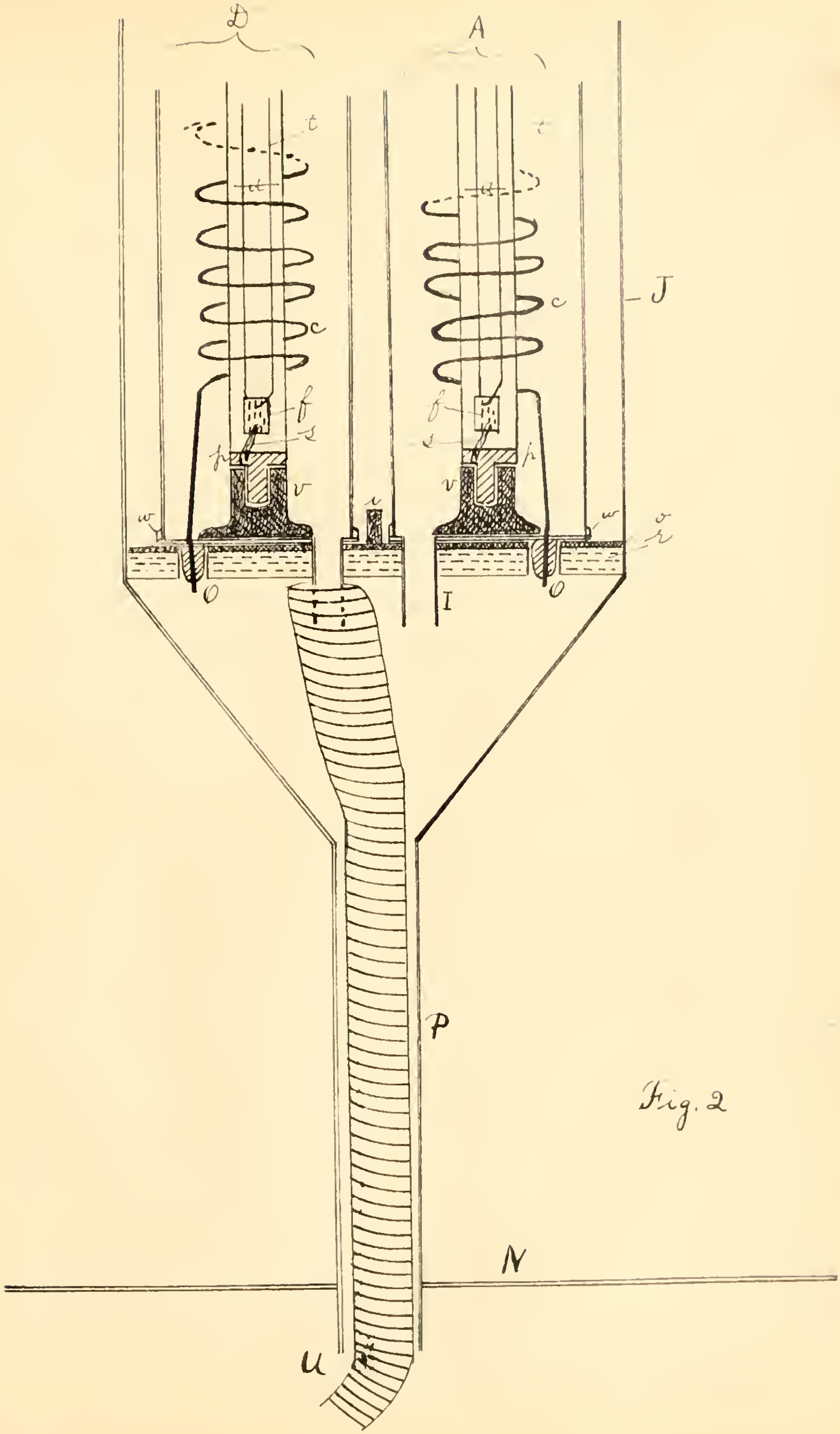


Fig. 2

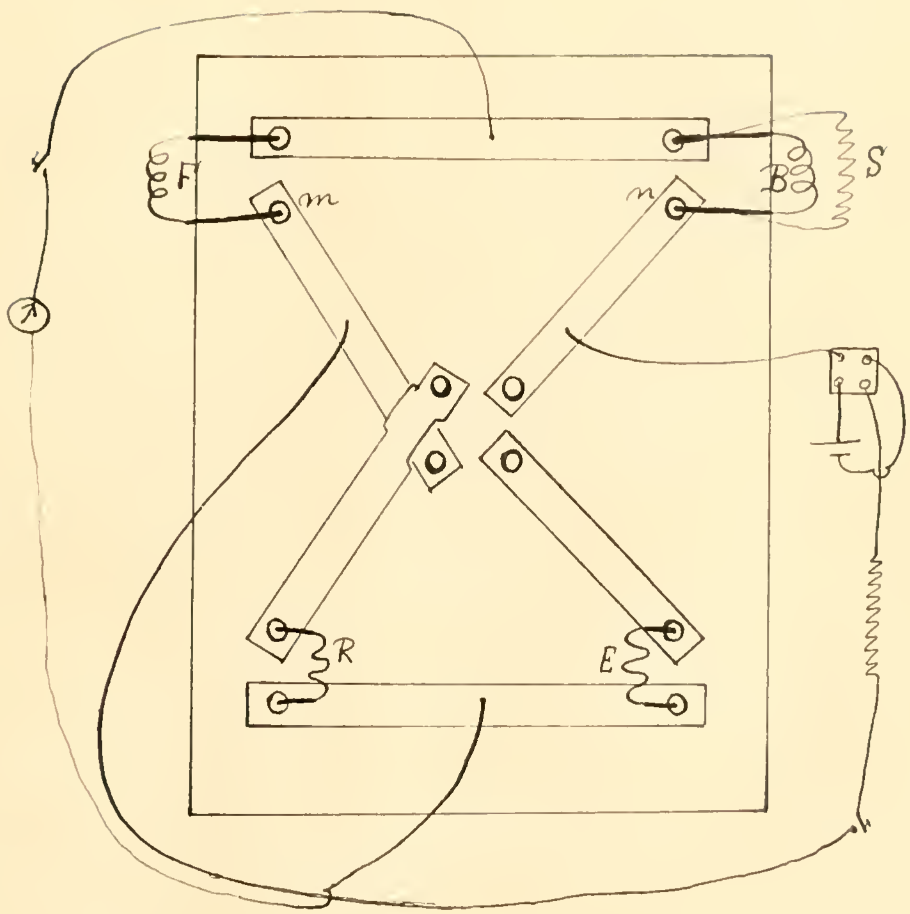


Fig 3